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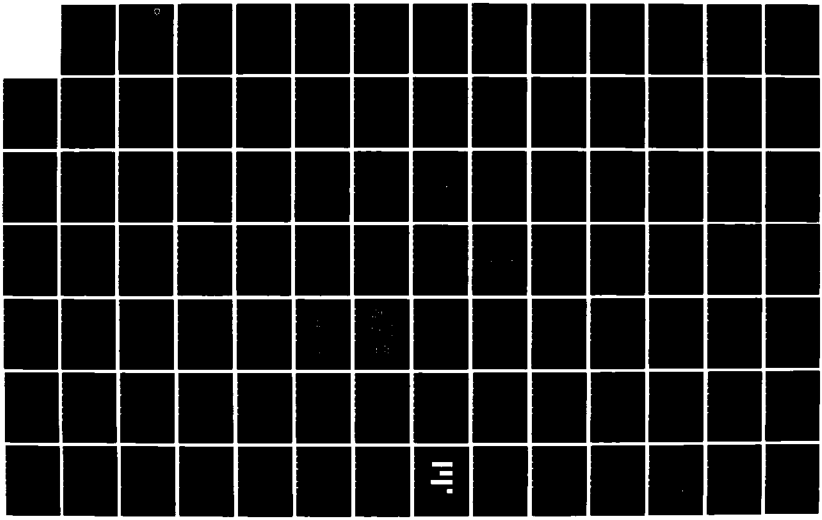

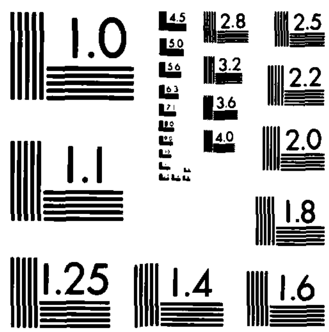

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ADVANCED TECHNOLOGY HELICOPTER LANDING GEAR PRELIMINARY DESIGN INVESTIGATION

J. K. Sen, M. W. Votaw, D. C. Weber

HUGHES HELICOPTERS, Inc.
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AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

This report presents the results of the preliminary design and analysis for Advanced Technology Landing Gear candidates for a utility class LHX. The landing gear designs included a standard retractable gear designed to normal sink speeds, a fixed crashworthy gear with energy absorbing capabilities up to 42 ft/sec, and a retractable crashworthy gear. All configurations were designed with kneeling capabilities, with special attention directed toward optimization of weight through use of advanced composite materials. The effects of crashworthiness design parameters, landing gear configuration, and materials on weight, cost and drag are presented. These results are used to develop weight sensitivity curves that are used in a trade-off analysis to establish recommended crashworthy design requirements with potential application in future military helicopter design.

The results of this program represent a significant advance in the understanding of the parameters which influence crashworthy landing gear and crushable fuselage weight. These findings will be integrated with a parallel ongoing effort and with past efforts in landing gear weight sensitivity leading to less costly, more weight-efficient crashworthy systems.

Mr. Geoffrey R. Downer of the Aeronautical Technology Division, Structures Technical Area, served as project engineer for this effort.

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This report describes the preliminary designs of two configurations of helicopter crashworthy landing gears: (1) with the trailing arms of the main gear coupled with a torque tube, which forces both shock struts to absorb the kinetic energy of an unsymmetrical crash impact, and (2) with the trailing arms uncoupled; i.e., the torque tube is replaced by a cross tube which is incapable of reacting the high torsional load of an unsymmetrical crash impact.

Retractable and fixed landing gears of both configurations have been designed, as well as a standard (noncrash-worthy) retractable landing gear. All landing gears are of tailwheel designs.

The designs apply the systems approach to crashworthiness where the total impact energy absorbed is shared by the landing gear, fuselage and seat. The designs of the crashworthy landing gears were completed after a preliminary investigation of crash impact at sink speeds up to 42 fps, roll angles up to ±20 degrees and pitch angles up to -10/+20 degrees. The crashworthy evaluations were made with program KRASH.

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A detailed analysis with KRASH was then conducted for all configurations of landing gears. The crashworthy conditions investigated for each gear design were combinations of five sink speeds, four roll angles and four pitch angles. Forty-eight impact conditions with the landing gear retracted were also investigated. The results of the KRASH analyses were consolidated into weight trend tables and curves to determine the increment in weight of energy absorbing material to make crash impact survivable. Based on the weight trend curves and cost analysis, a crashworthy design criterion was recommended.

This design criterion was the basis for updating the landing gear design. The designs identify the fabrication methods and processes for the landing gear. Estimates of cost and weight of the updated designs are also presented.

FOREWORD

The work reported herein was performed by Hughes Helicopters, Inc., Culver City, California, under Contract DAAK51-83-C-0039 for the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVSCOM),* Fort Eustis, Virginia. Mr. Geoffrey R. Downer is the Contracting Officer's Representative (Technical) and Mr. Drew G. Orlino is the Assistant Contracting Officer's Representative (Technical).

Design, structural analysis and weight sensitivity analysis were accomplished at HHI facilities in Culver City, California. The following HHI personnel have contributed to the work performed:

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SECTION 1

INTRODUCTION

This report describes the results of the work completed in all phases of the program for the preliminary design investigation on the advanced technology helicopter landing gear. The overall program consisted of three phases:

- Phase I - Landing Gear Design Development
- Phase II - Design Criteria Development
- Phase III - Design Update

The objective of the program was to conduct a preliminary design investigation of retractable and fixed landing gears in order to investigate the effects of various crashworthy design parameters. Three landing gears were designed:

a. A crashworthy retractable landing gear

b. A crashworthy fixed landing gear

c. A standard (noncrashworthy) retractable landing gear

The evaluation of the two crashworthy designs was with respect to the standard gear designed for normal design operating conditions. The three landing gears were designed for an LHX utility-class helicopter in the 6000-10,000-pound gross weight range. As a result of the investigation, a set of crashworthy design criteria was selected and the preliminary designs were updated to the selected criteria. The crashworthy design criteria were based on weight sensitivity and cost analysis of the crashworthy helicopter, for which drag had already been optimized. The design criteria, therefore, establish the highest cumulative frequency of occurrence of all survivable helicopter accidents acceptable while minimizing weight, cost and drag.

In the Phase I study, two baseline helicopters were identified and designed. Baseline BH1 helicopter was designed with the crashworthy retractable and fixed landing gears. Baseline BH2 helicopter is noncrashworthy and was designed for the standard landing gear; it is capable of the same payload as the BH1 helicopter. The gross weight of the crashworthy BH1 helicopter is 10,000 pounds.

The design of the crashworthy landing gears applies the systems approach where the total impact energy absorbed is shared by the landing gear, fuselage and seat. The crashworthy landing gears are designed to absorb 52 percent of the kinetic energy for an impact of 42 fps at 0 degree roll and 0 degree pitch. After the landing gear collapses, the fuselage deforms to absorb the remaining energy and the load-limiting seats stroke to maintain the acceleration on the occupants at survivable levels.

The designs of the baseline helicopters and the respective landing gears were completed by an iterative process by evaluating crashworthiness against weight, drag, ground resonance and cost. The design configuration of the crashworthy landing gears included a torque tube to couple the two trailing arms of the main gear. The torque tube thus transmits torque from one trailing arm to the other in an unsymmetrical impact forcing both shock-absorbing struts to absorb the impact energy. Material trade-off studies were conducted for potential landing gear components with fiber reinforced organic and metal matrices and materials requiring advanced processes. Crashworthiness with the gear extended was evaluated using program "KRASH" for symmetrical and nonsymmetrical impact conditions for sink speeds of 30 fps, 36 fps and 42 fps at impact attitudes of 0 to 20 degree roll angles and -10 to +20 degree pitch angles. Residual energy absorbing capability was also evaluated with program KRASH for symmetrical impact at 27 fps with the landing gear retracted. All impact conditions evaluated in Phase I were occupant survivable and pointed to the efficacy of the design in high roll impact conditions.

In the Phase II study, in addition to the coupled crashworthy landing gear, a second crashworthy landing gear configuration was designed. In the second configuration, the trailing arms of the landing gear were uncoupled; i.e., no provision was made to transmit torque through a torque tube from one trailing arm to the other. A total of 86 KRASH analyses were conducted for both coupled and uncoupled configurations with the gear extended and retracted. The weight sensitivity of the fixed gear was determined from the crash behavior of the retractable gear in the extended position. This was possible because the dynamics and energy absorption curve for the two systems are identical. The influence of the crash behavior of the fixed gear configuration is only on the landing gear (not the fuselage and crew seat) and due to weight only with all other parameters remaining unchanged. Since the fixed gear is less than 0.7 percent lighter than the retractable gear, the influence of weight is easily accounted for in the weight sensitivity analysis. In addition, 48 KRASH analyses were also conducted for fuselage impact, with the landing gear retracted at three sink speeds and the same roll and pitch attitudes as the impacts with the landing gear extended. The loads and deformations from KRASH analyses were used to size the landing gear components, fuselage and crew seats. The weights of each of the components were then calculated. The weight sensitivity analysis was then performed and the weight trend curves were constructed. The results of the analysis were used to develop a design criterion. The selected recommended design criterion is for an uncoupled landing gear.

The designs of the crashworthy retractable and fixed landing gears were revised in the Phase III study to meet the recommended design criteria developed in Phase II. The revised preliminary designs are for the uncoupled landing gear optimized for drag, cost and weight to meet the design criteria.

SECTION 2

CRASHWORTHINESS REQUIREMENTS AND DESIGN METHODOLOGY

2.1 GENERAL

The crashworthiness requirements given in Phase I are revisions to, and an expanded envelope of, MIL-STD-1290. The investigations conducted with these requirements were used for preliminary sizing and to identify specific impact parameters for further investigation in Phase II. The requirements of Phase II are less severe but required detailed investigation to complete the weight sensitivity analysis. Based on these investigations, the designs of the landing gears, together with their respective baseline helicopters, were completed by an iterative process to optimize the structure to the operational and crashworthiness requirements.

2.2 PHASE I CRASHWORTHINESS REQUIREMENTS

The Phase I crashworthiness requirements were utilized to define design concepts and establish specific design goals for detailed investigation in Phase II of the crashworthy landing gears. The landing gears must satisfy the normal operating design conditions of a standard (noncrashworthy) landing gear and also meet the impact envelope of sink speeds, roll angles and pitch angles shown in Figure 1. The impact surface is assumed to be infinitely rigid.

The normal operating conditions are those stated in:

- MIL-A-8863A, "Military Specification. Airplane Strength and Rigidity, Ground Loads for Navy Procured Airplanes," 12 July 1974 (which now supersedes MIL-A-8862), for ground handling and taxiing (except for a vertical load factor of 1.2 at the center of gravity for two- and three-point braked roll).

- MIL-S-8698, "Military Specification. Structural Design Requirements, Helicopters," 28 February 1958, for obstruction landing requirements.

- AMCP 706-201, "Engineering Design Handbook. Helicopter Engineering Part One, Preliminary Design," for transportability, symmetric and asymmetric landing conditions, and reserve energy requirements.

In addition, supplemental design requirements included horizontal speed conditions for limit and reserve energy sink speed, considerations for retracting the landing gear, and designing for fatigue loads.

- INFINITELY RIGID IMPACT SURFACE
- NO FUSELAGE CONTACT: 20FPS, + 10° ROLL, -5° TO +15° PITCH
- IMPACT DESIGN ENVELOPE
  - VERTICAL SINK SPEED
  - VERTICAL SINK + 25 FPS HORIZONTAL SPEED

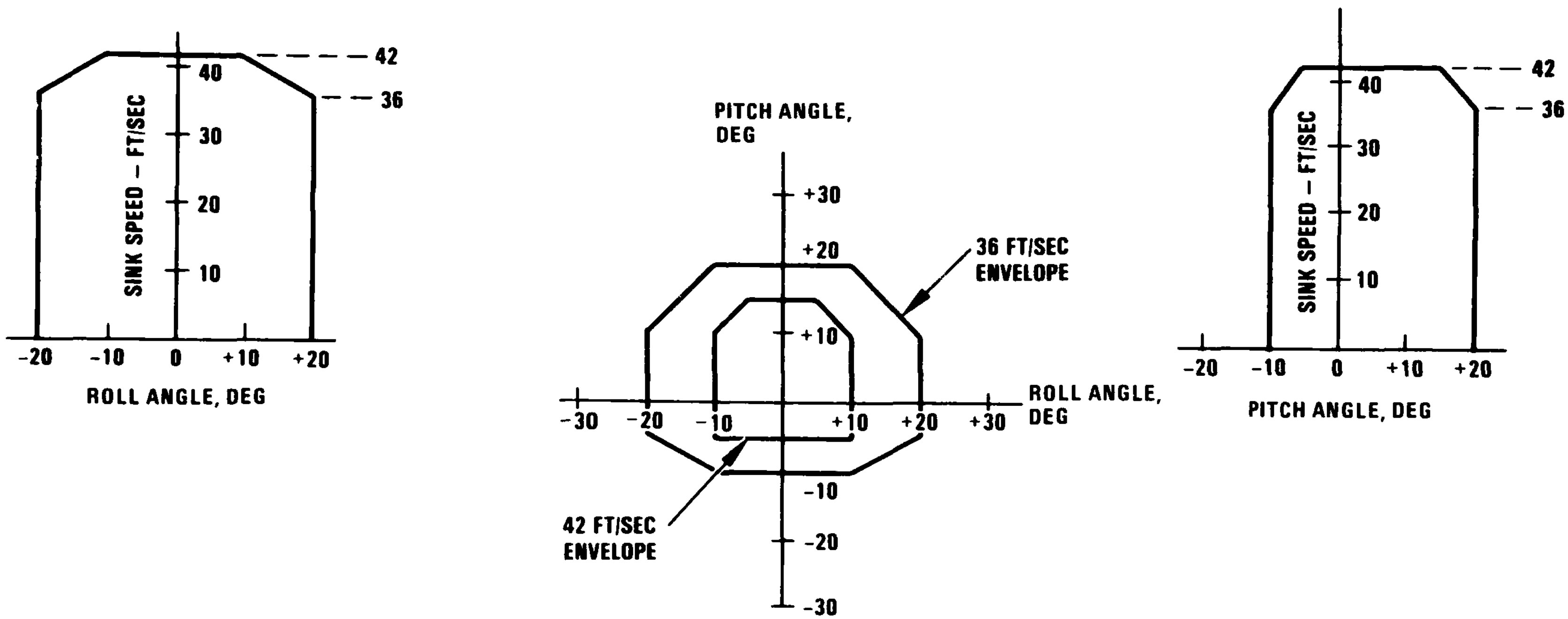


Figure 1. Crashworthy requirements for the retractable and fixed landing gears.

2.3 PHASE II CRASHWORTHINESS REQUIREMENTS

The Phase II crashworthiness requirements were investigated in detail to determine the influences of crashworthiness conditions on the weight of the helicopter. The study includes the effects of different crash impacts with the landing gear extended and with it retracted. The impact conditions with the landing gear extended are combinations of each of the following:

- Sink speed: 42, 36, 30, 20, 15 fps
- Roll angle: 0, 5, 10, 15 deg
- Pitch angle: -5, 0, +7.5, +15 deg

The impact conditions with the landing gear retracted are combinations of each of the following:

- Sink speed: 35, 30, 25 fps
- Roll angle: 0, 5, 10, 15 deg
- Pitch angle: -5, 0, +7.5, +15 deg

2.4 DESIGN METHODOLOGY

The design methodology is an iterative process fashioned to first assess the system size requirements, then to complete the preliminary design and, lastly, to finalize the detail designs. The analytical tool used to verify the crashworthy design features is program KRASH (Reference 1). The design iteration flow chart is shown in Figure 2.

The methodology requires that the helicopter be first sized. For preliminary sizing, the helicopter in the neighborhood of the occupant is first designed, including all the major items and the attachment points. The design should also include features to meet the requirements of the probable impact conditions and of the human tolerance levels. The helicopter structure is then modelled for program KRASH by simulated masses, springs and beams. The initial sizing of the components can be made with a simple (five-mass) KRASH model. As the design develops, refinements are made for drag, ground resonance, results of stress analysis, materials, weight and cost. In addition, the KRASH model increases in complexity in order to more correctly evaluate loads, deformations and crash parameters of accelerations, rates and durations of accelerations, and Dynamic Response Index (DRI) of the occupant. With each stage of KRASH analysis, structural design and concept are refined to meet the crashworthiness requirements. The acceptable design is one which meets the crashworthiness requirements and is optimized for weight and cost.

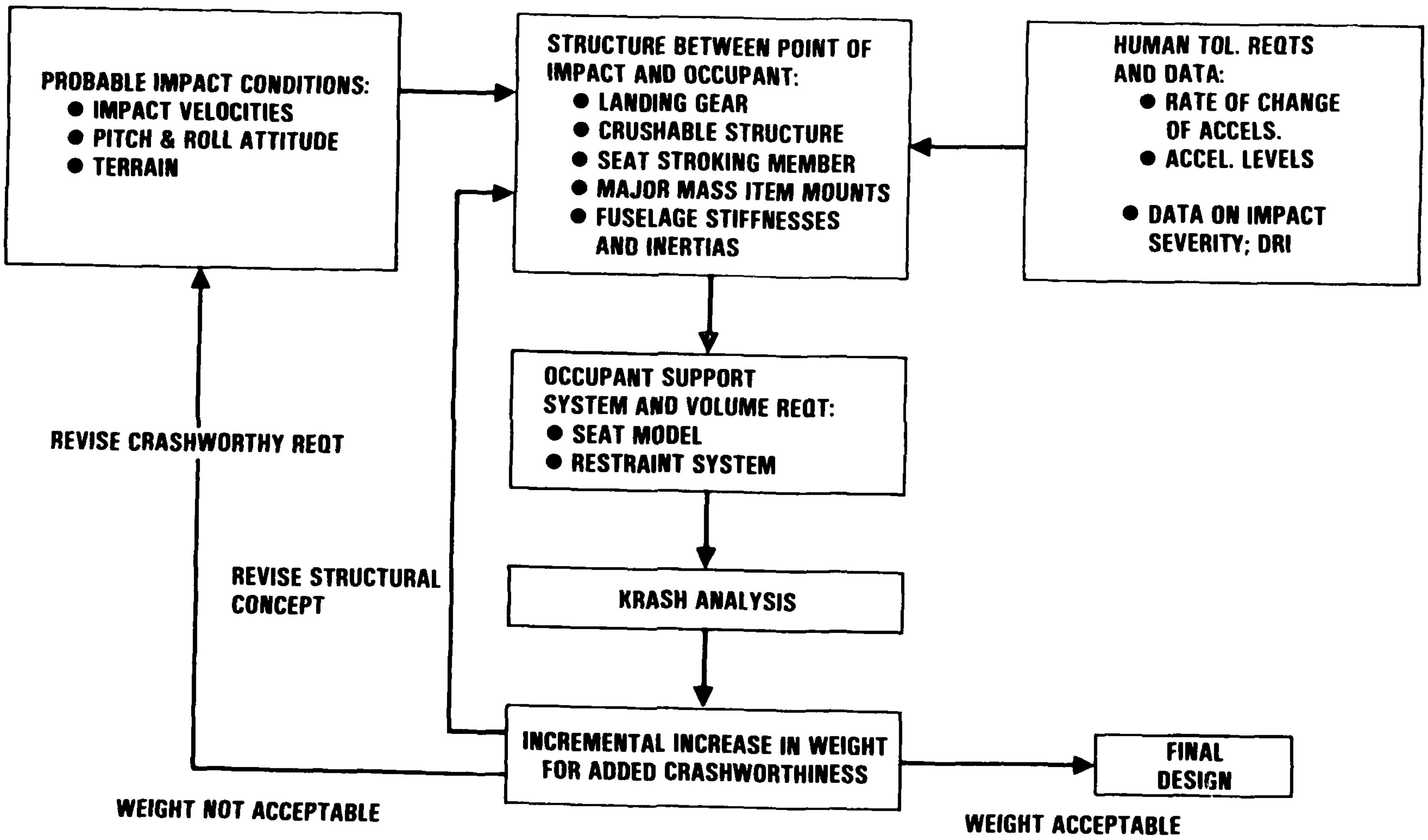


Figure 2. Iteration flowchart for crashworthy design methodology.

SECTION 3

PRELIMINARY DESIGN OF THE LANDING GEARS

3.1 THE DESIGNS AND DESIGN CONSIDERATIONS

The preliminary designs of five landing gears are presented. The five designs consist of

a. The crashworthy retractable landing gear with coupled main gear trailing arms

b. The crashworthy fixed landing gear with coupled main gear trailing arms

c. The standard (noncrashworthy) retractable landing gear

d. The crashworthy retractable landing gear with uncoupled main gear trailing arms

e. The crashworthy fixed landing gear with uncoupled main gear trailing arms

In this study of crashworthy landing gears, the systems approach to crashworthiness is applied, where the absorption of the total impact energy is shared by the landing gear, fuselage and seat. From the moment of contact, the landing gear begins to stroke and the shock strut absorbs the kinetic energy. After the fuselage contacts the ground, the landing gear continues to stroke while additional energy is absorbed through fuselage deformation. The crew seats stroke during the deformation to attenuate peak accelerations and to limit them within human tolerance levels. The principle of the systems approach is shown in Figure 3.

The crashworthy landing gear configuration selected is a trailing arm, tailwheel design. A tailwheel configuration has been identified in Reference 2 as the minimum weight solution to the crashworthy landing gear design problem. Other advantages of the tailwheel configuration include:

- Overall crew and passenger safety is enhanced because this design easily allows the landing gear to be placed outside of, thus minimizing the possibility of landing gear intrusion into, the cabin area.

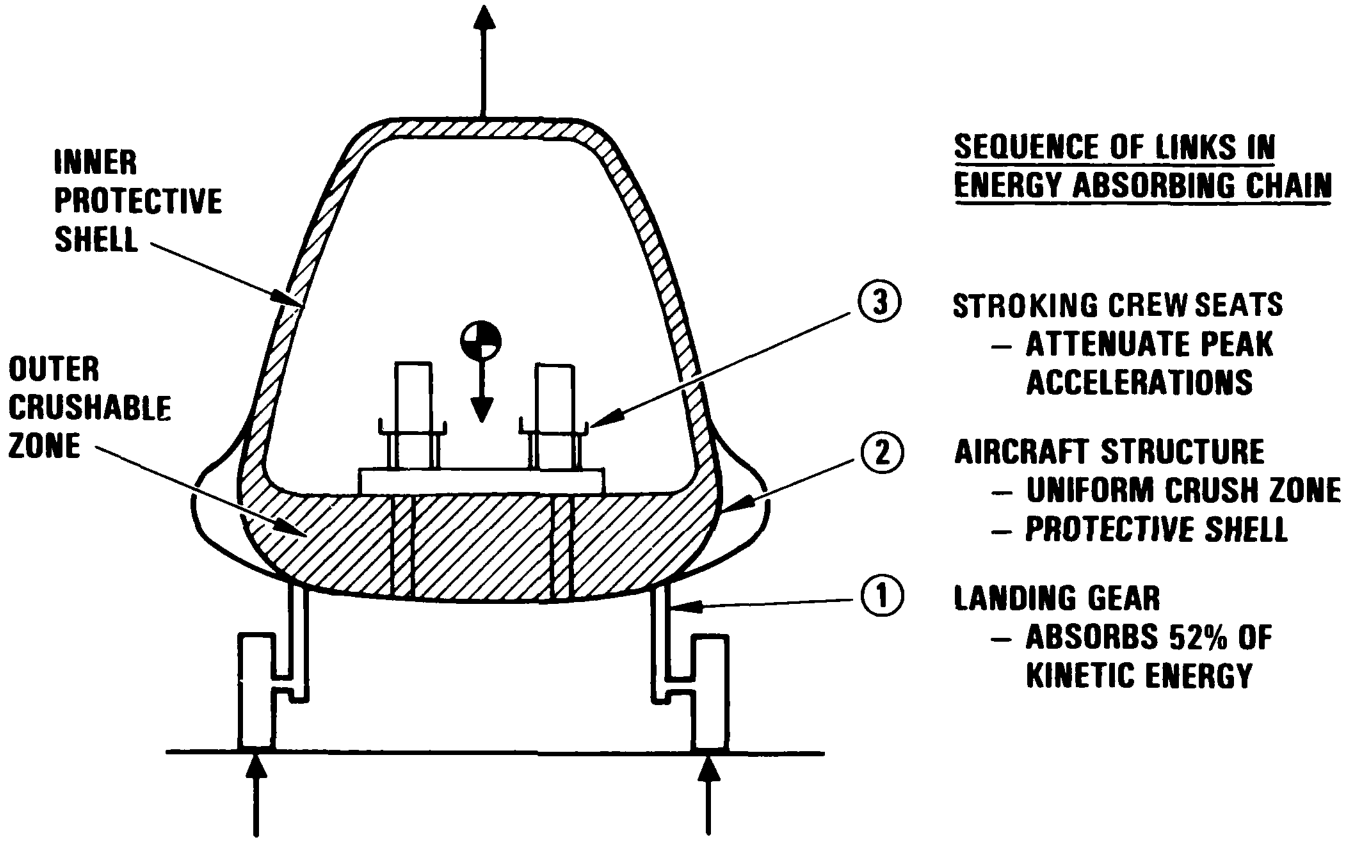


Figure 3. Principle of systems approach to crashworthiness.

- The tailwheel landing gear design allows nose down rolling takeoffs, a very dangerous maneuver with other gear configurations, such as a tricycle landing gear.

The trailing arm design for the main landing gear has been selected for the following reasons:

- The energy absorption of the landing gear is relatively insensitive to side loadings. (See Figure 4.)

- The rearward rake of the main landing gear is safer than other designs in a forward velocity rough terrain or obstructed runway landing because of the landing gear's natural tendency to deflect up and back, over the obstruction.

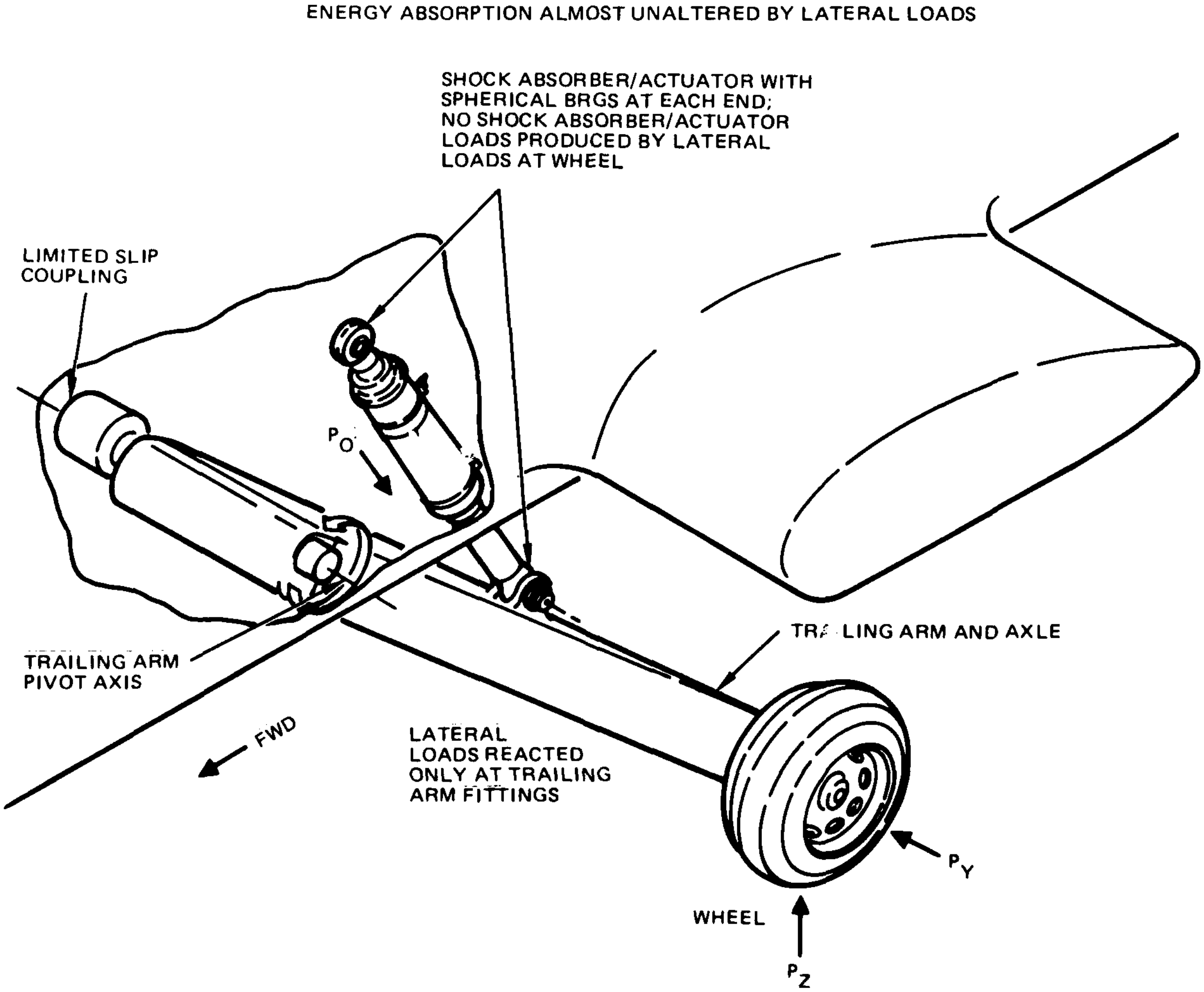


Figure 4. Reaction of lateral loads in trailing arm type landing gear.

- Short, direct load paths for the crash loads that utilize the same structure that is needed for flight and landing loads.

- Energy absorption is provided through large displacements of the shock struts. This reduces the accelerations imposed on the occupants.

- With proper strut geometry, nearly constant ground load factors are achieved throughout the landing gear stroke, thus optimizing energy absorption while minimizing landing gear loads.

Each trailing arm of the coupled landing gear includes a torque tube. The two torque tubes are connected by a limited slip coupling which ties the trailing arms together. This allows the left-side and right-side gears to act independently of each other for ground handling and gear resonance purposes, and allows both gears to act dependently of each other for high roll vertical crashes. The coupled landing gear, therefore, activates one more item of the system, which otherwise would remain passive, to absorb crash-impact energy in an unsymmetrical impact. In the case of the uncoupled landing gears, the torque tube is replaced by a cross tube which is not designed to transmit the high torque of crash impact from one trailing arm to the other. In the uncoupled landing gear designs, which also utilize the systems approach to crashworthiness, only the shock strut(s) of the respective landing gear(s) contacting the ground absorbs the impact energy.

The systems approach necessitates designing the fuselage along with the landing gear. Since this study will result in crashworthy design criteria based on weight for crashworthy landing gears in comparison to a standard landing gear, two baseline helicopter designs are established to allow for an accurate estimate of the increases in weight of the total system to meet the crashworthy requirements. The landing gear configurations are designed for use with a 10,000-lb gross weight helicopter.

The designs of the crashworthy fuselage and landing gears are based on KRASH analyses described in Section 4. The results of KRASH analyses determined the following preliminary crashworthiness design parameters for the helicopter:

- 7.5g landing gear

- 25.5 inches of ground stroke

- 15g fuselage

- 9 inches of crushable zone in the lower fuselage with 7 inches of effective stroke available to absorb the kinetic energy

- 14 inches of seat stroke

3.2 ESTABLISHING BASELINE CONFIGURATIONS

Two baseline LHX utility helicopters have been designed. The baseline helicopter for all crashworthy landing gears is derived from the 1982 SCAT helicopter design (CT5) of Contract DAAK50-78-G-004 (Reference 3). This baseline crashworthy helicopter is referred to as BH1. The baseline helicopter for the standard retractable landing gear is referred to as BH2. The empty weight of the BH2 baseline helicopter is lighter than BH1 because it is noncrashworthy.

The definitions of the baseline helicopters include the identification and location of the major mass items, the major structural members and the load paths for the design landing loads. The major mass items are the rotor systems, transmission, engines, fuel cells, crew and other occupants. The structural members are the nose cone, cockpit and cabin areas, tail boom and landing gear hard points. The bulkheads and lower fuselage have been defined to the extent that the load paths from the landing gear can be identified and the weights of crushable material can be calculated. The helicopters have tailwheel landing gears and are designed for a crew of two seated side by side and six troops seated three abreast.

3.2.1 BH1 Baseline Helicopter

The BH1 baseline helicopter was selected for the retractable and fixed crashworthy landing gears with coupled and uncoupled trailing arms as shown in Figure 5. The fuselage is 443 inches long, 78 inches wide and 66 inches high. The retractable main landing gear retracts into external fairings which extend outboard 4 inches on either side of the fuselage. The tail gear is fully retractable. For the coupled and uncoupled fixed landing gears, the fairings are not required but blisters are added to reduce fuselage drag. The BH1 helicopter with retractable and fixed configurations of the coupled and uncoupled landing gears utilizes the retraction mechanism of the combination of actuator and shock strut to kneel the helicopter for transportation in a C-141 aircraft.

The crashworthiness design requirements of the BH1 helicopter are

a. Maintain protective living space for occupants

b. Keep accelerations to survivable levels

c. Prevent breakaway of heavy mass items (if breakaway is properly designed for, this can be beneficial)

d. Avoid blade strike

e. Prevent post-crash fires

f. Permit easy egress from crashed aircraft

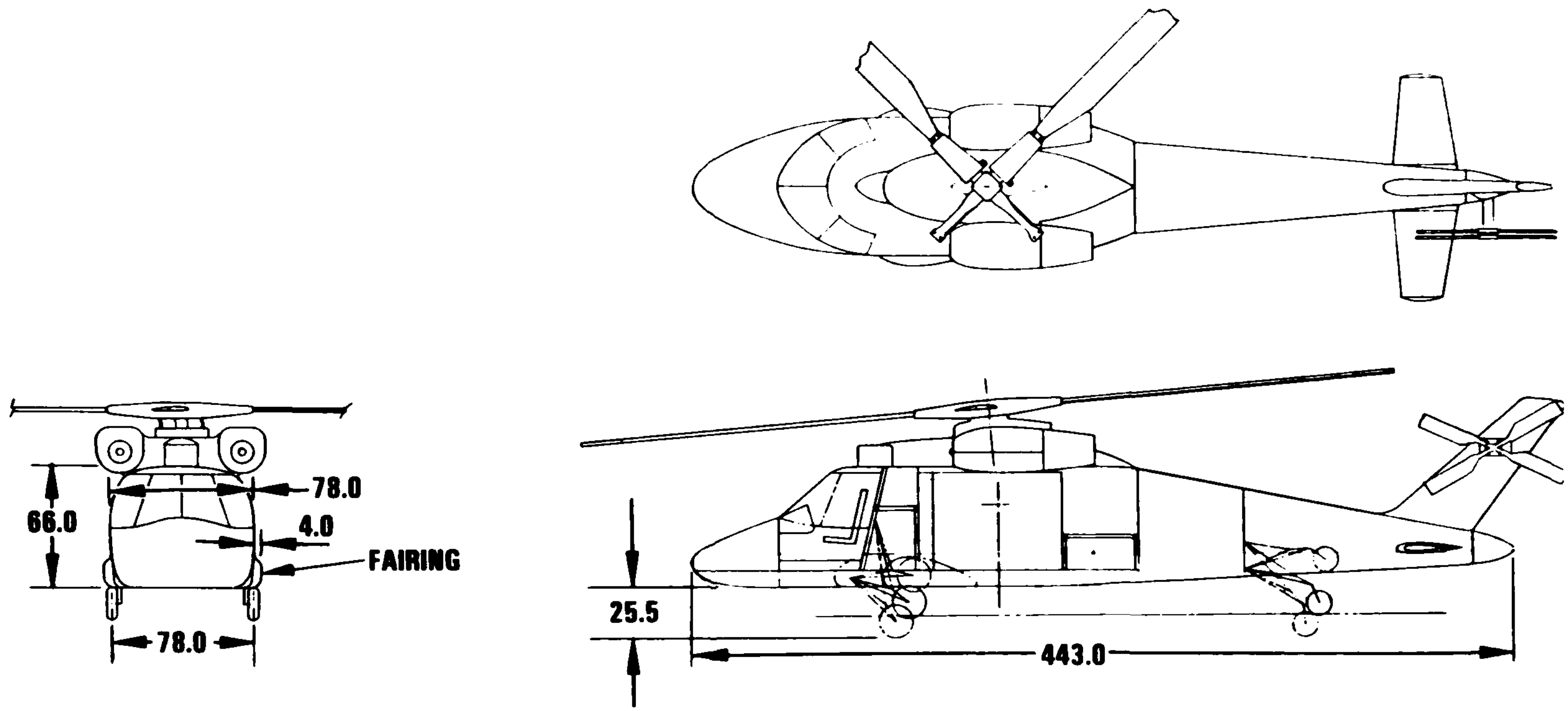


Figure 5. Baseline helicopter BH1 for crashworthy landing gears.

The first three requirements are met, in part, with two energy-absorbing keel beams in the lower fuselage that provide 9 inches of crushable material. The sides of the helicopter are also suitably reinforced with crushable material. The bulkheads are located and strengthened to provide adequate support for the crew and heavy mass items. The seats are positioned to provide for standard human engineering requirements and adequate seat stroking.

The keel beams are of composite sandwich construction having Kevlar 49/epoxy skins with fibers oriented at ±45 degrees to the vertical axis of the helicopter, and Nomex honeycomb core. The load-deflection curve for a sample of the keel beams is shown in Figure 6. In a crash impact condition, the keel beams will absorb the remaining aircraft kinetic energy following the collapse of the landing gear. The 9-inch-deep keel beams are designed to deform a maximum of 7 inches. Details of the crash impact parameters and the efficacy of the choice of this keel beam construction are given in Reference 4.

3.2.2 BH2 Baseline Helicopter

The BH2 baseline helicopter for the standard (noncrashworthy) landing gear has fully retractable main and tail gears. The main landing gear extends below the fuselage after doors open to expose them. The BH2 helicopter, shown in Figure 7, is 443 inches long, 72.8 inches wide and 63 inches high. The available volume inside the BH2 helicopter is the same as that of the BH1 helicopter and has the same kneeling capability for transportation in a C-141 aircraft.

3.2.3 Weights of the Baseline Helicopters

The breakdown of the gross weights of BH1 and BH2 helicopters is given in Table 1. The gross weights of BH1 helicopter with coupled and uncoupled landing gear are given in the table. The gross weights of BH1 are for crash impact conditions requiring the greatest energy-absorbing material in the system. The weights are for landing gears designed with conventional materials, i.e., without the use of composite materials. This condition for BH1 with a retractable coupled landing gear is designed to meet a crash impact at 42 fps and an impact attitude of 15-degree roll and +15-degree pitch. The most severe impact condition for BH1 with uncoupled landing gear is for 42 fps at 15 degrees roll and 0 degree pitch.

The differences in the weights of the heaviest BH1 helicopter with coupled landing gear and BH2 helicopter are 635 pounds. This weight of BH1 with coupled landing gear is still 19 pounds lighter than the maximum increase possible if all energy-absorbing structures were to deform completely to their design maximum. This maximum possible increase in weight with coupled landing gear is 654 pounds but is never required in practice. The breakdown of 654 pounds is given in Table 2. The BH1 helicopter with the uncoupled landing gear is 53 pounds lighter than that with coupled landing gear. The weight of BH1 with uncoupled landing gear, shown in Table 1, is only 1 pound lighter than the maximum possible increase of 583 pounds. The design with the uncoupled landing gear,

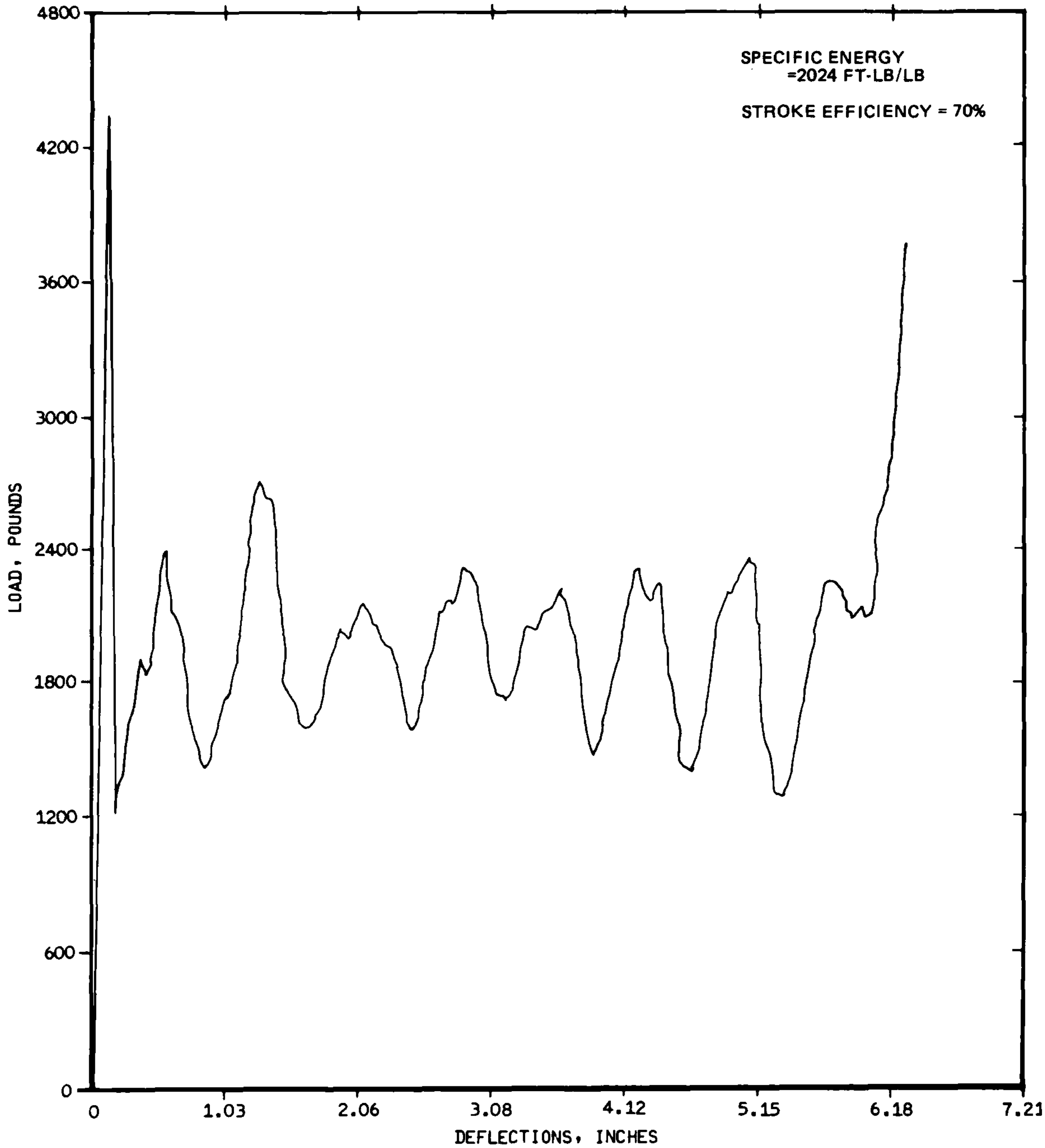


Figure 6. Load-deflection curve for the sandwich beams used in the keel beam construction of BH1 helicopter.

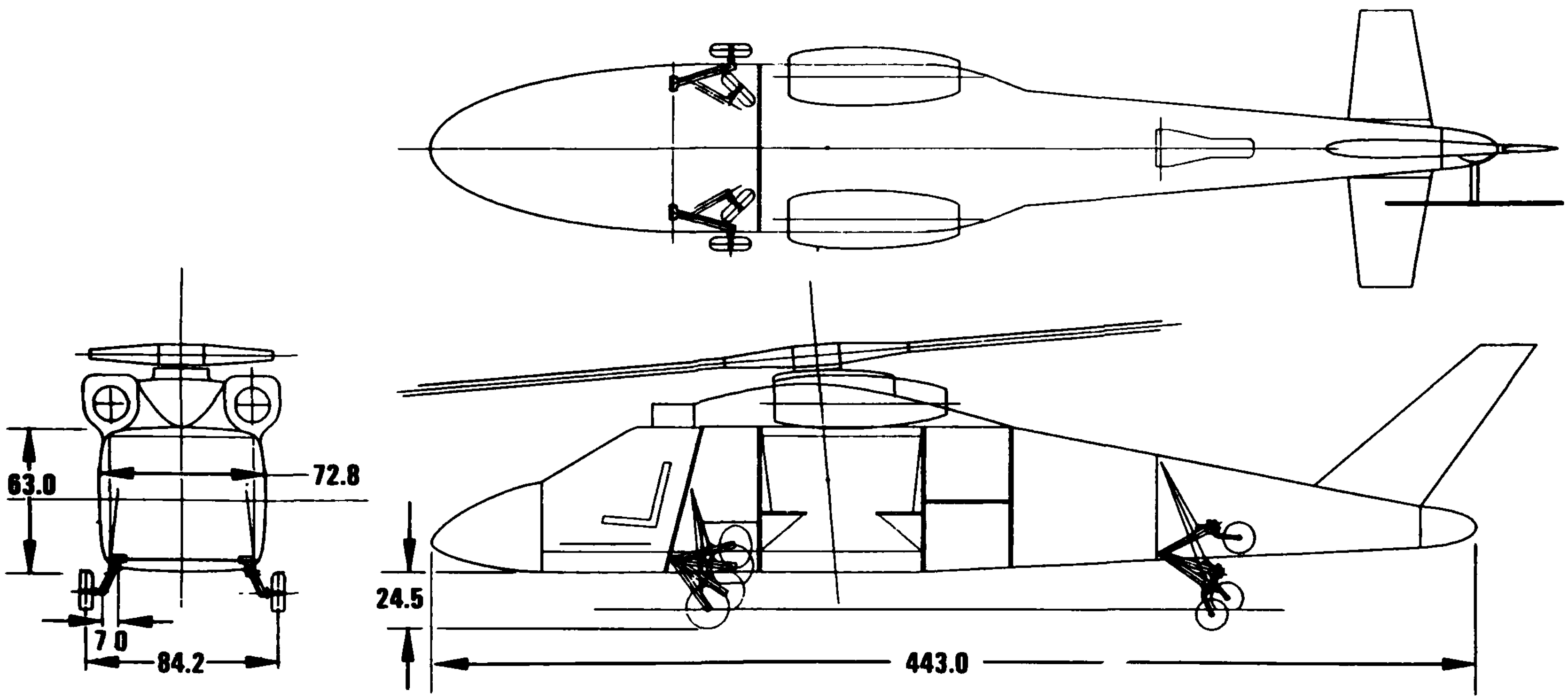


Figure 7. Baseline helicopter BH2 for standard retractable landing gear.

TABLE 1. COMPARISON OF GROSS WEIGHTS OF MAXIMUM CRASHWORTHY RETRACTABLE AND STANDARD HELICOPTERS

Item	Helicopter Weight, lb		
	BH1 Crashworthy Landing Gear		BH2 Standard Landing Gear
	Coupled	Uncoupled	
Crew (2)	500	500	500
Payload	1,763	1,763	1,763
• 6 Troops	• 1440	• 1440	• 1440
• Other	• 323	• 323	• 323
Fuel	1,550	1,550	1,550
Tail Rotor	67	67	67
Body	958	1,045	866
Landing Gear	559	414	296
Exhaust (Black Hole)	94	94	94
Nacelle	139	139	139
Fuel System	284	284	154*
Armor	230	230	230
Furnishing (Troop Seat, etc.)	303	308	167
Mission Equipment	919	919	919
Common Weight	2,634	2,634	2,620
Gross Weight	10,000	9,947	9,365

*The fuel system is not crashworthy.

TABLE 2. MAXIMUM POSSIBLE INCREASE IN WEIGHT REQUIRED FOR CRASHWORTHINESS BY RETRACTABLE LANDING GEARS

Item	Landing Gear Configuration	
	Coupled	Uncoupled
Main and Tail Landing Gear	262 lb	118 lb
Fuselage Structure	105 lb	178 lb
Crew Seats (2)	44 lb	44 lb
Troop Seats (6)	66 lb	66 lb
Seat Support Structure	12 lb	12 lb
Rotor Support Structure	4 lb	4 lb
Engine Drive System	4 lb	4 lb
Engine Mounts	10 lb	10 lb
Fuel System	130 lb	130 lb
Roll Bar	17 lb	17 lb
Total	654 lb	583 lb

NOTES: (1) This maximum weight for the coupled landing gear is never required because all energy absorbing structures do not deform simultaneously to their design maximum.

(2) The landing gears are made of 300M alloy steel.

therefore, utilizes all the energy-absorbing capacity of the system, with no reserve available, for the most severe impact condition. The breakdown of 583 pounds is also given in Table 2. Since the maximum practical differences in weights between BH1 and BH2 are 635 pounds and 582 pounds, these figures will be used in subsequent calculations. To determine the empty weights of BH1 and BH2 helicopters, 3853 pounds must be removed from their respective gross weights, as shown in Table 3.

TABLE 3. BREAKDOWN OF WEIGHTS TO BE REMOVED TO OBTAIN MANUFACTURED EMPTY WEIGHT

Crew	500 lb
Payload	1,763 lb
Fuel	1,550 lb
Engine Oil	40 lb
	3,853 lb

3.3 DESIGN OF CRASHWORTHY RETRACTABLE COUPLED LANDING GEAR

The crashworthy retractable coupled landing gear, designed for the BH1 baseline helicopter, is designed around a simply articulated trailing arm gear with a torque tube interconnect. The distinctive design features of the crashworthy landing gear are the torque tube interconnecting the two trailing arms and the combination of actuator and energy-absorbing strut. A conceptual drawing of the landing gear is shown in Figure 8. The reasons for choosing the trailing arm design have already been explained in Section 3.1.

The purpose of connecting the trailing arms by the torque tube is to transmit, in an unsymmetrical crash condition, half of the crash loads from the ground-contacting down-side landing gear to the energy-absorbing strut of the up-side landing gear. The interfaces between the trailing arms and the torque tube are designed to allow 5 degrees of uncoupled rotation between the two trailing arms. The 5-degree slip allows independent movement of the trailing arms during ground handling operations.

The purpose of using a combination of actuator and energy-absorbing strut is to utilize the stroking action of the strut as the retraction mechanism. The double-acting strut reduces the weight of the landing gear by eliminating the need for a dedicated retraction actuator.

The geometry and positioning parameters of the landing gear are summarized below. The requirements of crash impact have been discussed in Section 2 and the results of KRASH analysis and the manner in which they influence the design are presented in Section 4. The geometry and positioning of the landing gear are based on the following requirements (Reference 5):

- Ground handling, for a given ground height:
  - 0.8g braking load, determines the minimum longitudinal distance between the main gear and the helicopter cg

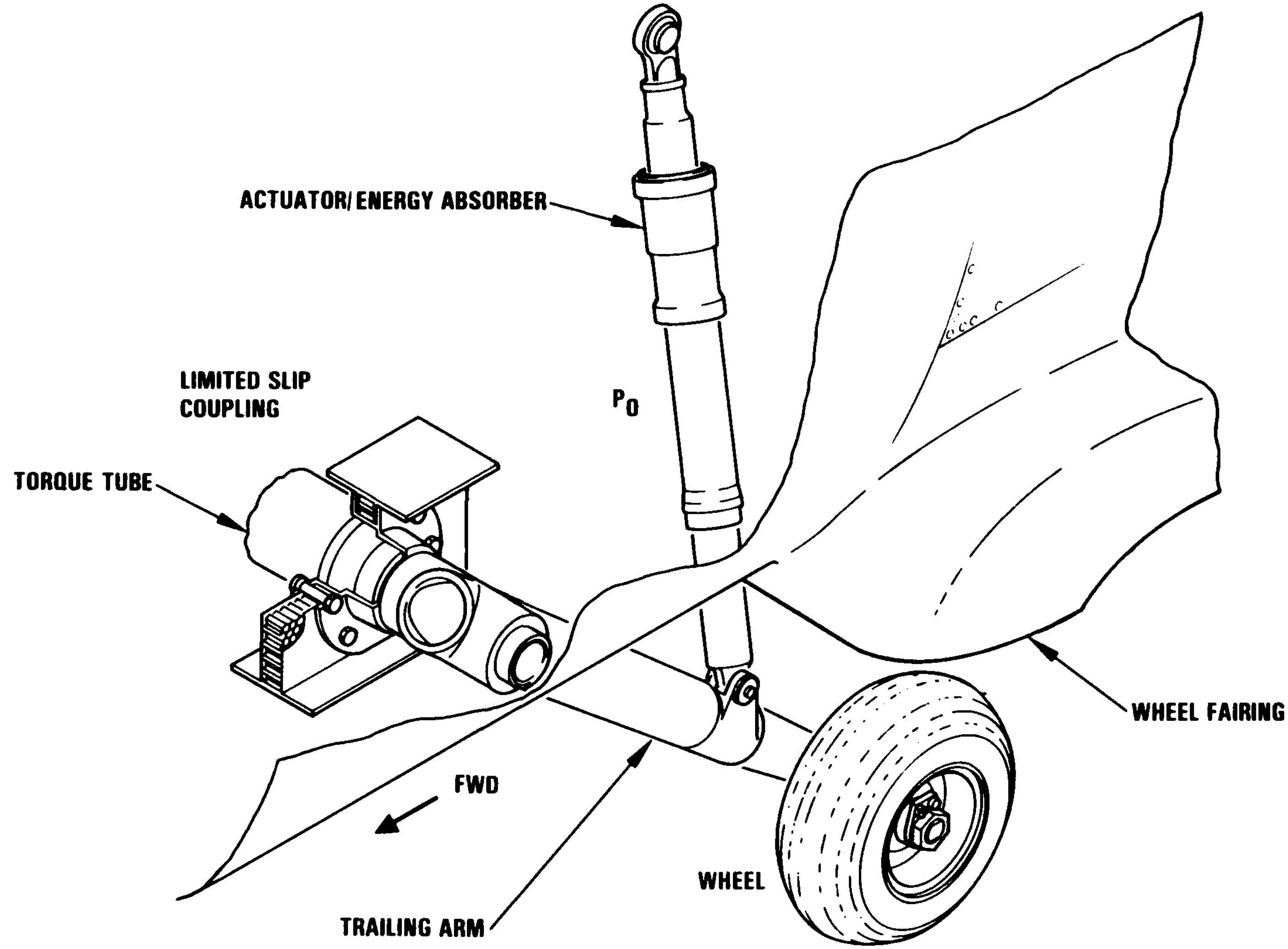


Figure 8. Concept features of the crashworthy coupled landing gears.

- 0.5g turning load, determines the minimum lateral distance between the main gear and the helicopter cg.

- Structural:

  - landing gear hard points should be close, along the longitudinal axis, to the helicopter cg in order to minimize the lengths of the load paths and the magnitudes of the loads

  - hard points should be located near structural members capable of reacting the landing loads.

- Aerodynamic:

  - landing gear stance width should be minimized to reduce drag area

- Energy Absorption:

  - ground clearance should be maximized to reduce fuselage loading in crash conditions.

The first three requirements are optimized when the ground clearance is minimized. This is in direct opposition to the energy-absorption requirement. An attempt to optimize all of the conditions has lead to the concept of the dual-position landing gear. The helicopter would initially contact the ground with the gear in the fully extended "crash" position. Under normal loads, the helicopter would automatically settle to a "low" ground handling position.

This dual-position concept allows the longitudinal and lateral positioning of the landing gear to be determined for a low ground handling height and yet provide a high ground clearance for the energy-absorption and fuselage loading requirements. The concept of a simply articulated gear was motivated by the requirement for kneeling the helicopter for the convenience of transporting it and for increased energy-absorption capability with the gear retracted.

The overall landing gear configuration is designed to minimize the degrees of motion involved in the retraction/stroking process. This was done to minimize the discontinuities in the load paths through the landing gear. These discontinuities would take the form of joints and pivots, the interfaces between separate components, and would necessarily represent high weight penalties. Additionally, the retraction kinematics utilize the same mechanisms for the kneeling and energy-absorbing motion.

The landing gear geometry is given in Figure 9 and has the following parameters:

- Ground height, extended = 25.5 inches

- Ground height, handling = 16.0 inches

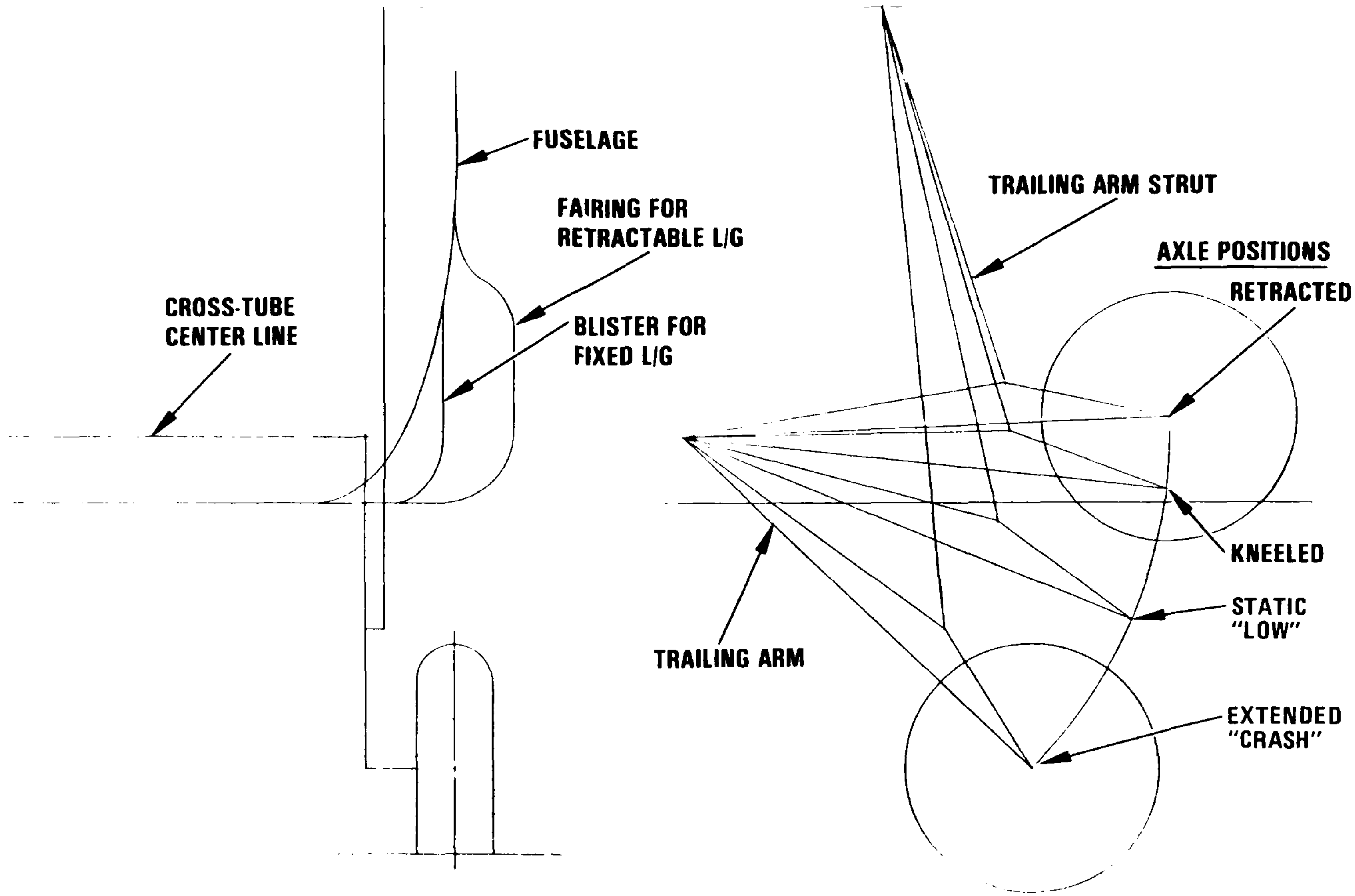


Figure 9. Geometry of crashworthy retractable and fixed main landing gears.

- Geometry or shape factor = 1.52 average
- Main/Tail weight distribution = 73:27
- Tread width = 78.0 inches
- Kneeled wheel extends 5.5 inches below fuselage (giving 4.0 inches of ground clearance)
- Retracted wheel extends 2.8 inches below fuselage

The tail landing gear will be fully retractable and has been positioned well forward of that in the AH-64A helicopter, with consequent lower weight for the tail boom. The kinematics of the tail gear are shown in Figure 10.

In the final design, all components of the landing gear are made from 300M alloy steel. The decision to choose this material is explained in Section 3.10. The geometry of the torque tube is shown in Figure 11. The outer diameter of 7 inches is dictated by the 9 inches of available space in the lower fuselage. The trailing arm of the main and tail gears is shown in Figures 12 and 13, respectively, and the actuator-shock strut is shown in Figure 14.

3.4 DESIGN OF CRASHWORTHY FIXED COUPLED LANDING GEAR

The crashworthy fixed coupled landing gear is identical in design to the crashworthy retractable landing gear except that the retracting hydraulics, gear door mechanisms, fairings and up-locks are absent. The crashworthy fixed landing gear is also used on the BH1 baseline helicopter. The designs of the main and tail landing gears are, therefore, based on the trailing arm concept, and on a torque tube for the main landing gear. The geometry of the gear is identical to that shown in Figure 9 except the retracted position is not available.

3.5 DESIGN OF STANDARD RETRACTABLE LANDING GEAR

The design of the standard retractable landing gear is based on the same ground handling, structural and aerodynamic requirements as those given for the retractable crashworthy landing gear. This landing gear is designed without a metering orifice on the strut in order to have a positive effect on reliability and cost reduction. The kinematics of the standard retractable landing gear are shown in Figure 15.

The standard retractable main landing gear has an articulated trailing arm and is designed with 300M alloy steel for the BH2 baseline helicopter. The main gear is pivoted about a hinge, which permits the gear to be first retracted up by the trailing arm strut, and then rotated and retracted fully into the wheel bay with the help of a small secondary actuator (Figure 15). The tail gear is

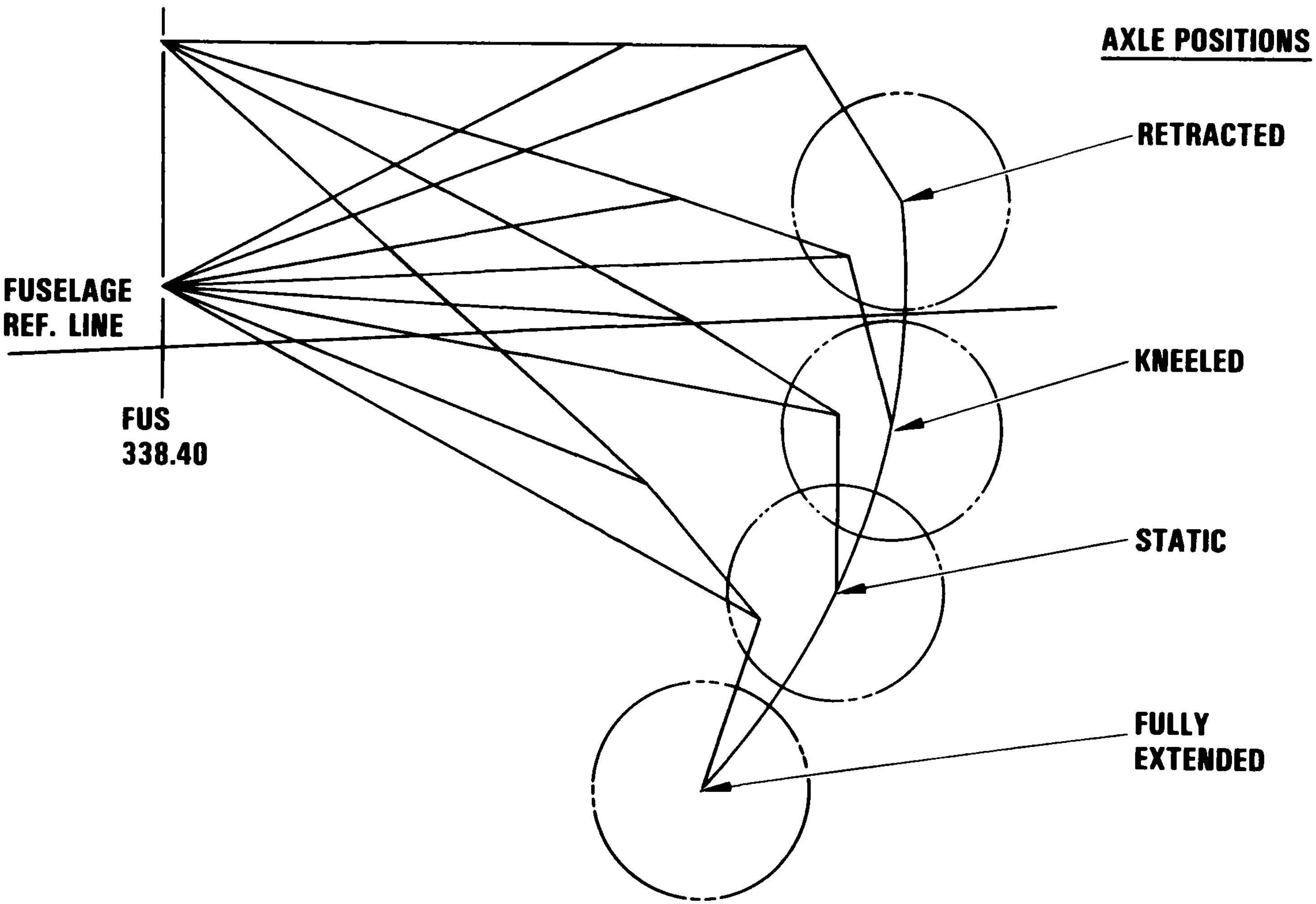


Figure 10. Kinematics of crashworthy tail landing gear.

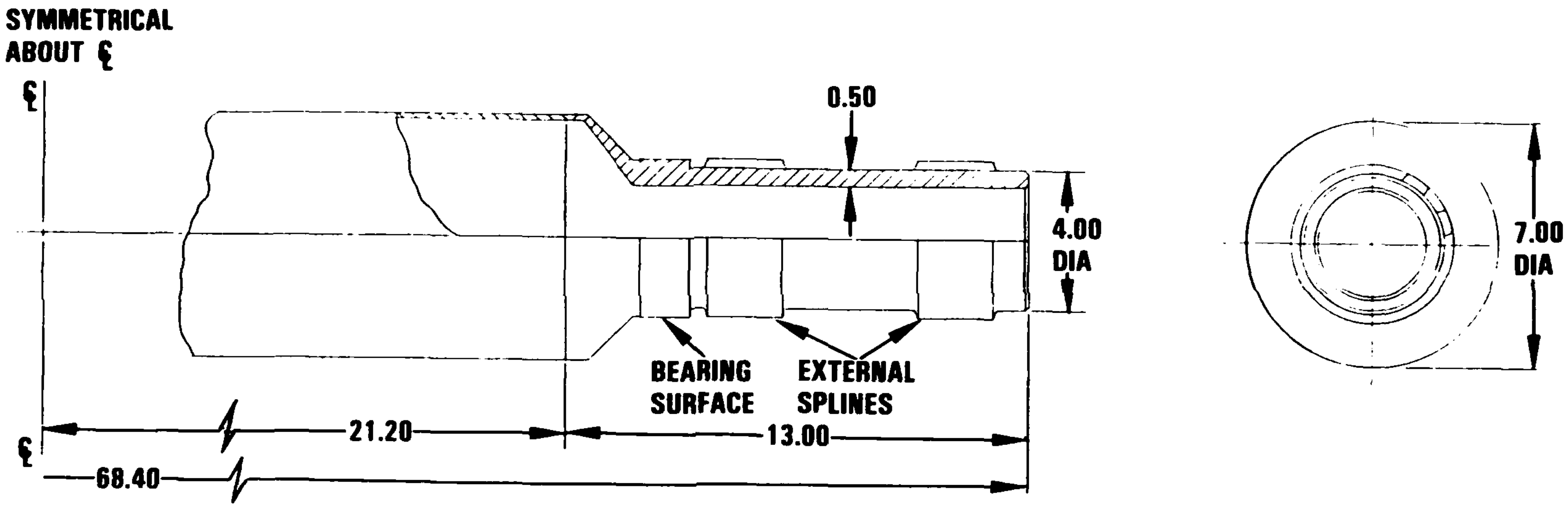


Figure 11. Torque tube of crashworthy coupled main landing gear.

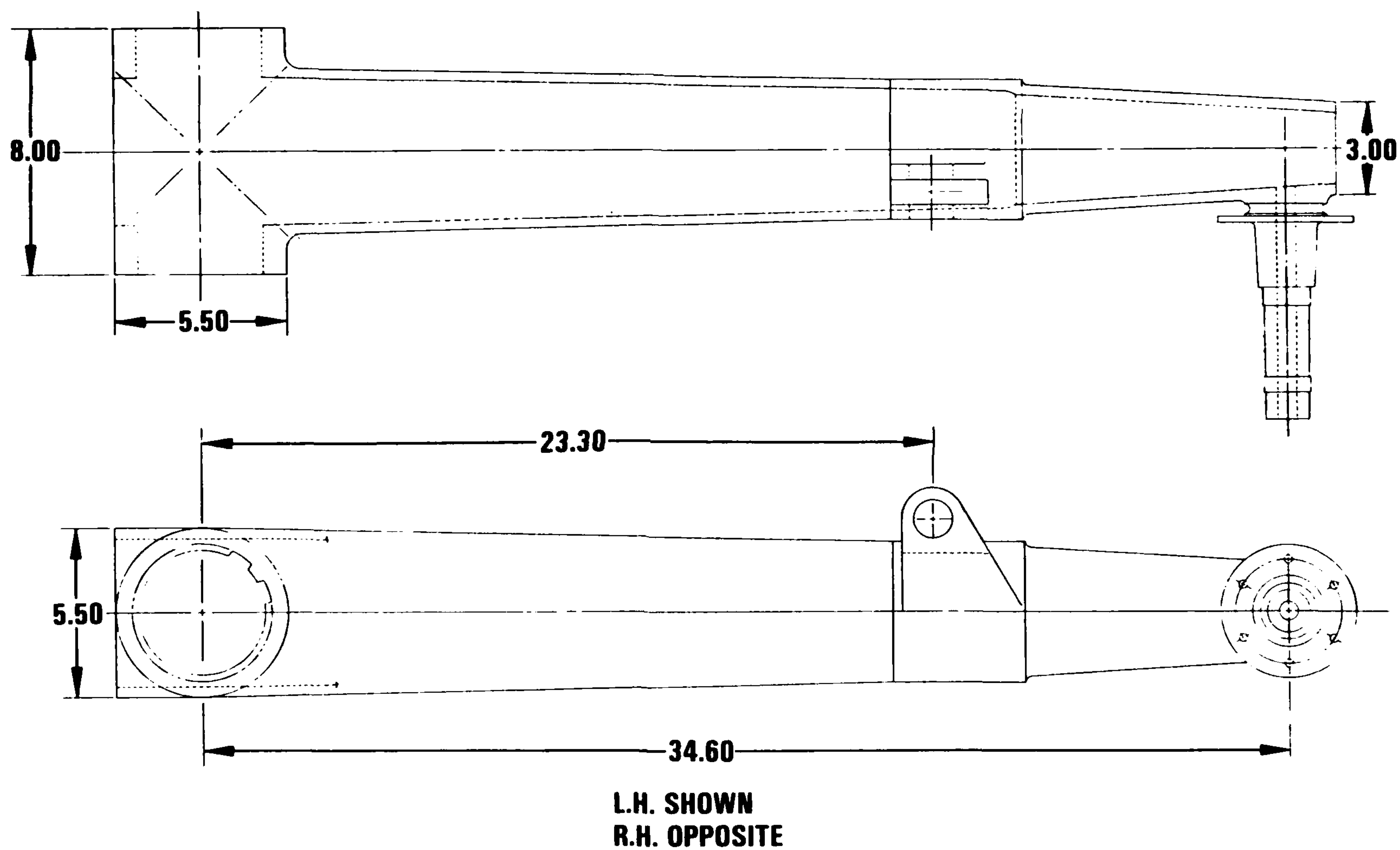


Figure 12. Trailing arm of crashworthy coupled main landing gear.

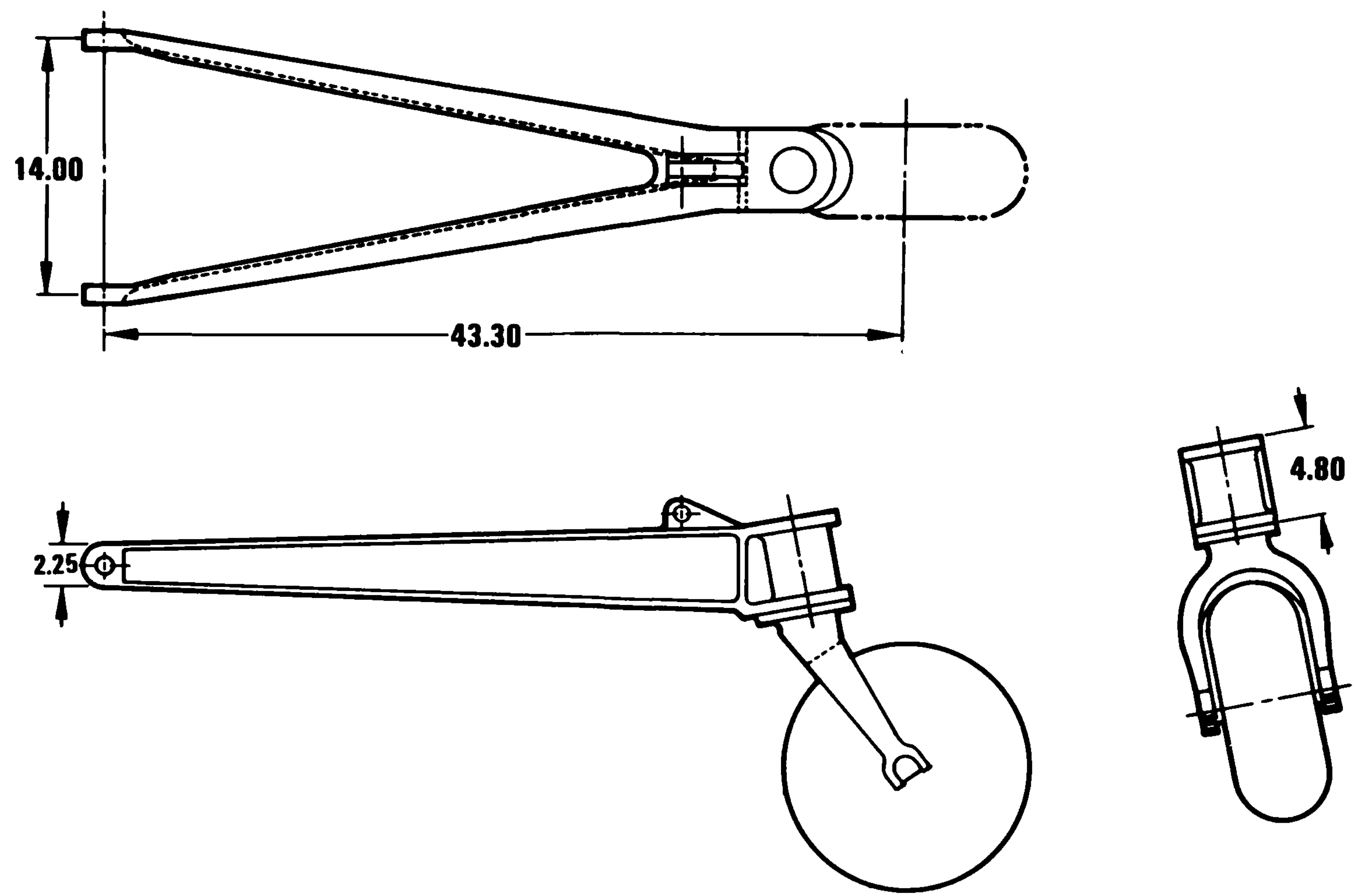


Figure 13. Trailing arm of retractable crashworthy tail landing gear.

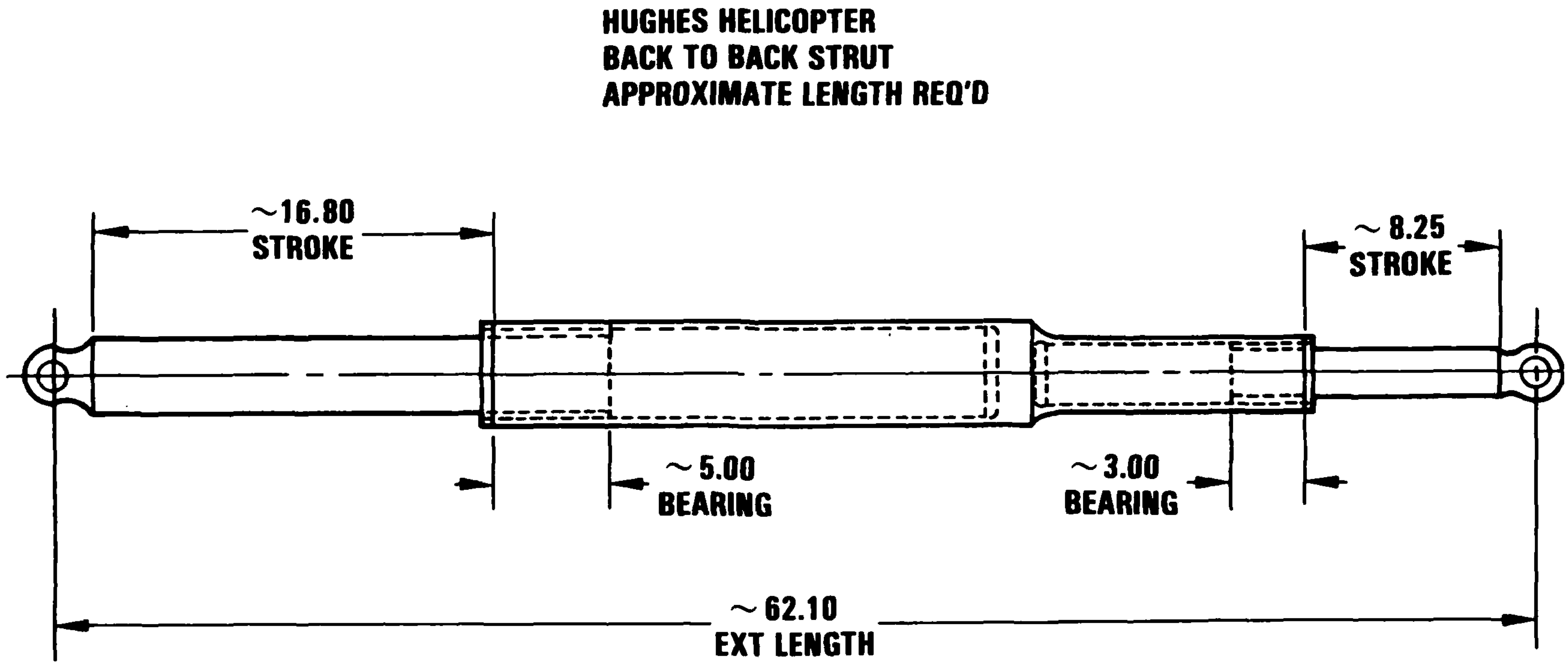


Figure 14. Combination actuator/energy-absorbing strut for the crashworthy main landing gear.

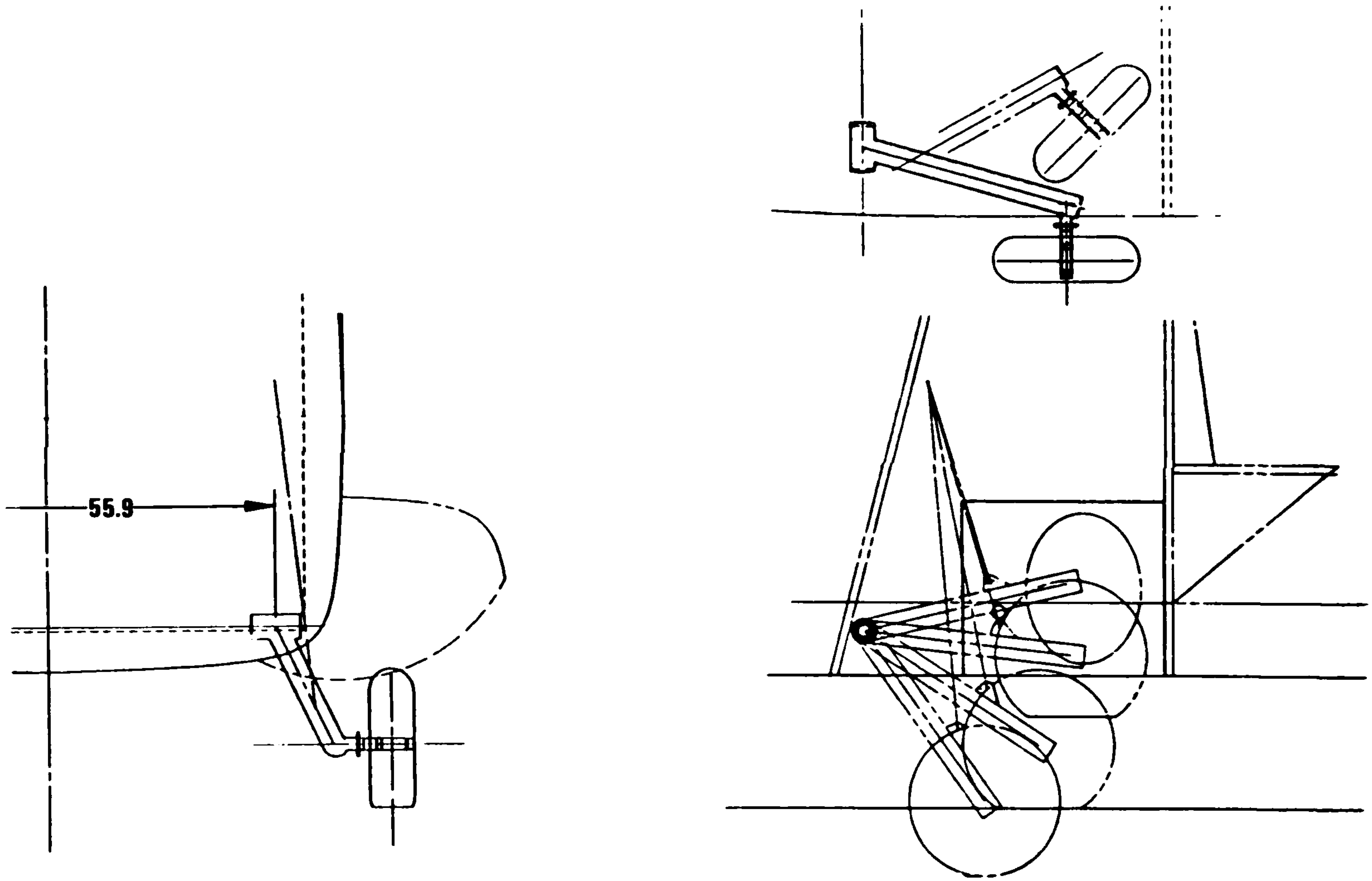


Figure 15. Kinematics and retraction of standard retractable main landing gear.

also designed with a trailing arm and retracts fully into the tail boom, Figure 16. The landing gear parameters are

- Ground height, extended - 24.5 inches
- Ground height, handling - 16.25 inches
- Main/Tail weight distribution - 80:20
- Tread width - 84.2 inches

3.6 DESIGN OF CRASHWORTHY UNCOUPLED LANDING GEARS

Preliminary designs of two crashworthy uncoupled landing gears were also completed in Phase II. The uncoupled retractable and fixed landing gears were designed to determine their relative weight advantages over corresponding coupled landing gears. The major change in the design is replacing the steel torque tube of the coupled gear with a steel cross tube for the uncoupled gear. The cross tube runs laterally across the airframe and is connected to it by pivot fittings at each side. The trailing arms pivot on the projecting ends of the cross tube allowing the wheel travel to occur restrained only by the oleo. This arrangement has the advantage of reacting all lateral and drag loads on the wheel at the cross tube while loading the oleo only in the axial direction. The cross tube and trailing arms of the uncoupled gears are lighter than their counterparts in the coupled gears because they react much lower loads and no torque. The cross tube, and its assembly to the trailing arm, is shown in Figure 17. The weights breakdown is shown in Tables 1, 2 and 3. Detailed descriptions of uncoupled landing gear designs are given in Section 9, DESIGN UPDATE. The material trade-off study for the cross tube is discussed in Section 3.10.2.

3.7 WEIGHTS OF THE LANDING GEARS

The weights of the landing gears are composed of seven elements shown in Table 4. The differences in weight between the three gears are in the weights of the torque or cross tube, trailing arms and shock struts. These three components of the landing gear are made of 300M alloy steel as shown in the table. The weights of the other elements in the table remain unchanged for all impact conditions. The weights of the crashworthy landing gears shown in Table 4 are for the heaviest gears required to absorb the energy for the most severe impact condition, which is at 42 fps and 15 degrees roll, with +15 degrees pitch for the coupled gear and 0 degree pitch for the uncoupled gear. These weights of the retractable landing gear are included in the helicopter weights in Table 1.

3.8 DRAG ESTIMATES

Throughout the design process of the baseline helicopters and the landing gears, drag estimates have been made to continuously refine the design and reduce parasitic drag. The configuration of the crashworthy landing gear analyzed is shown in Figure 18. The final drag estimates of the three landing gears and of the two helicopters are given in Table 5.

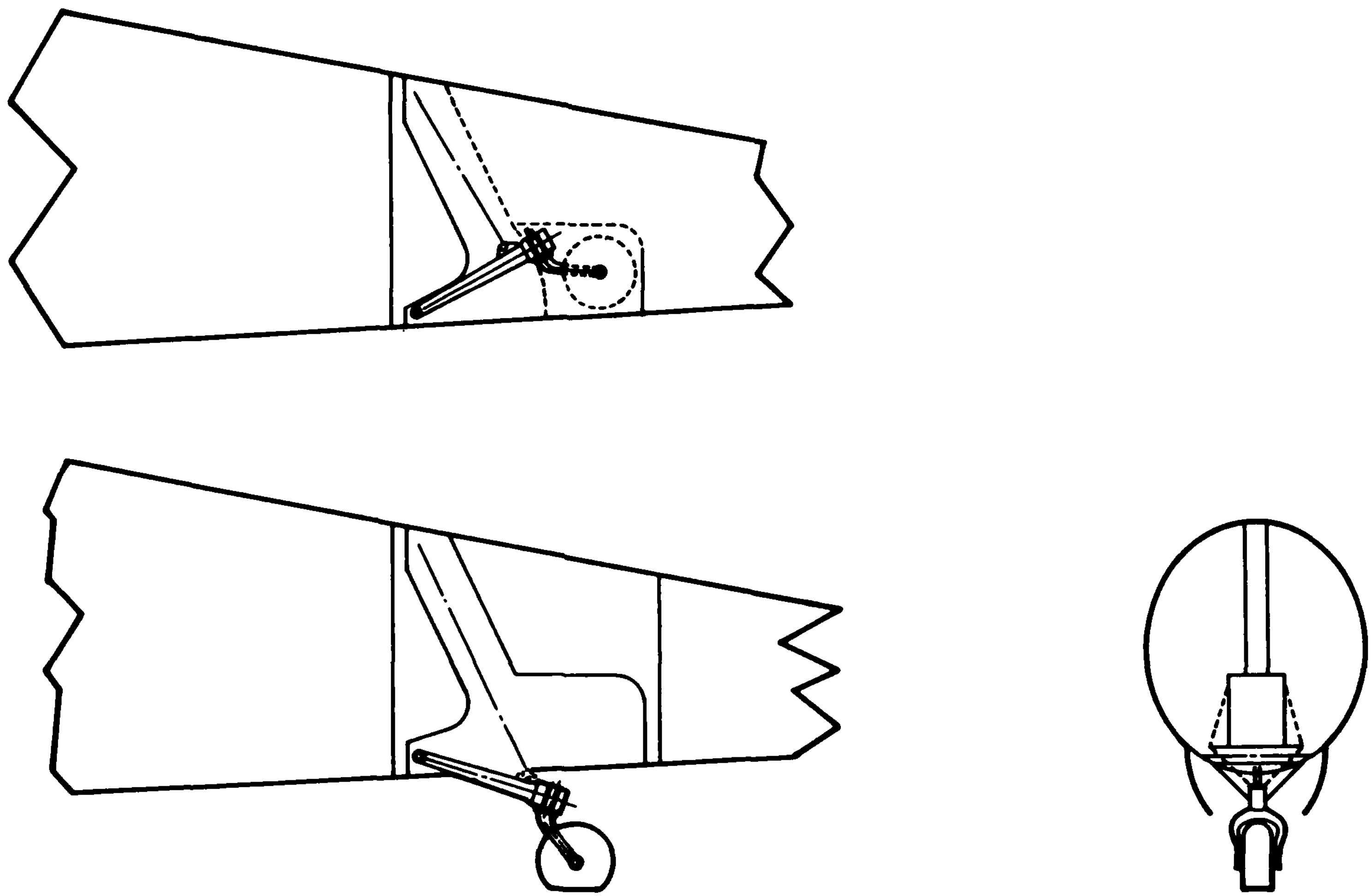


Figure 16. Standard retractable tail landing gear.

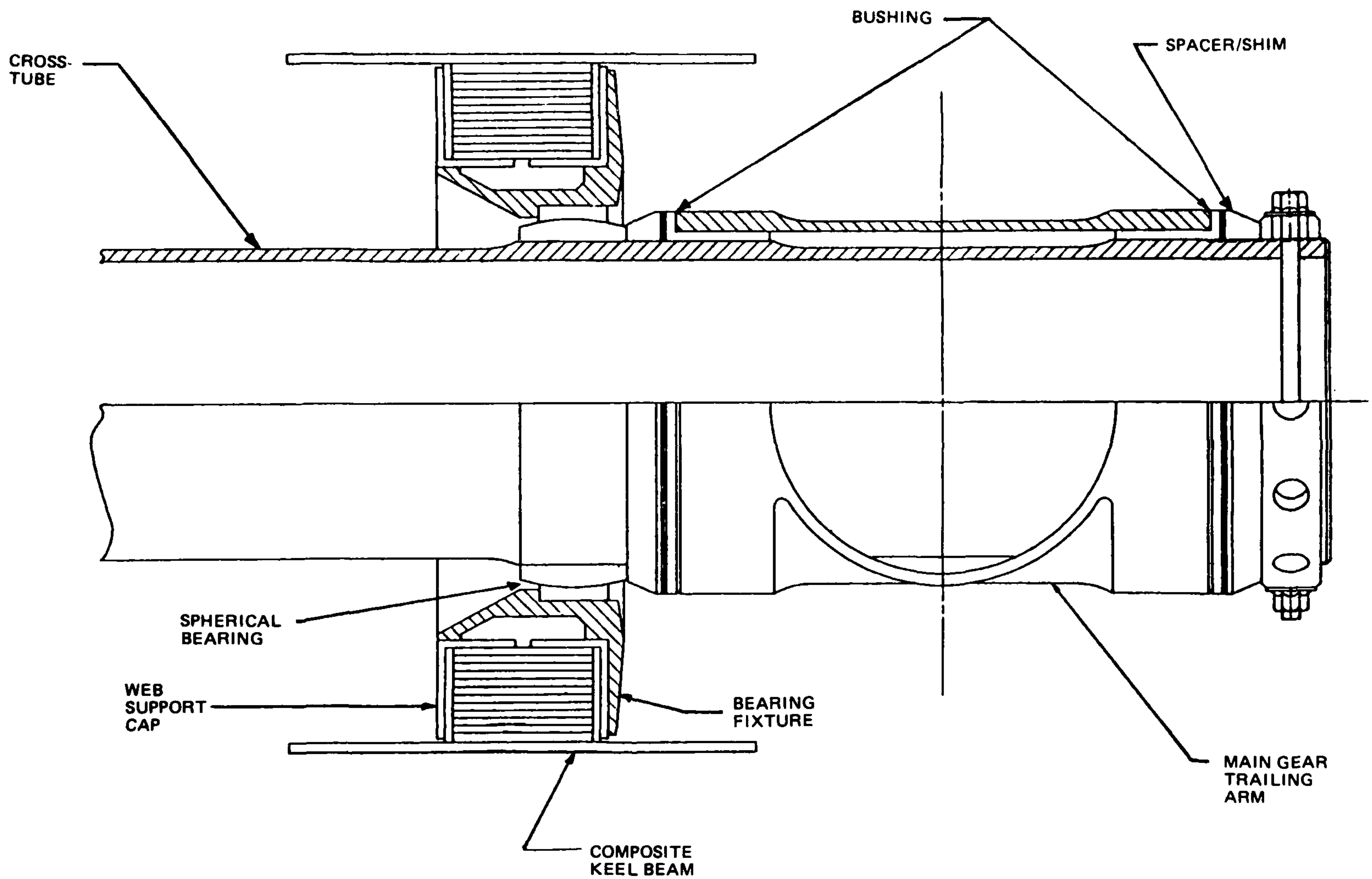


Figure 17. Steel cross tube/trailing arm assembly of crashworthy uncoupled landing gear.

TABLE 4. WEIGHTS OF LANDING GEAR COMPONENTS MADE OF 300M ALLOY STEEL

Component	Crashworthy Coupled				Crashworthy Uncoupled				Standard	
	Retractable		Fixed		Retractable		Fixed		Retractable	
	MLG	TLG	MLG	TLG	MLG	TLG	MLG	TLG	MLG	TLG
Rolling Assembly	68	10	68	10	68	10	68	10	68	10
Torque Tube/Cross Tube	164	-	164	-	43	-	43	-	22	-
Gear-Fuselage Attach. Ftgs	15	10	15	10	15	10	15	10	15	10
Trailing Arms	75	22	75	29	52	22	52	29	44	8
Shock Strut	128	20	117	12	128	20	117	12	65	10
Attachment Fittings	12	5	12	5	12	5	12	5	12	5
Controls	26	3	-	-	26	3	-	-	24	3
Subtotals	488	70	451	66	344	70	307	66	250	46
Totals	558		517		414		373		296	

NOTE: The weights shown for crashworthy landing gears are for the severest impact condition.

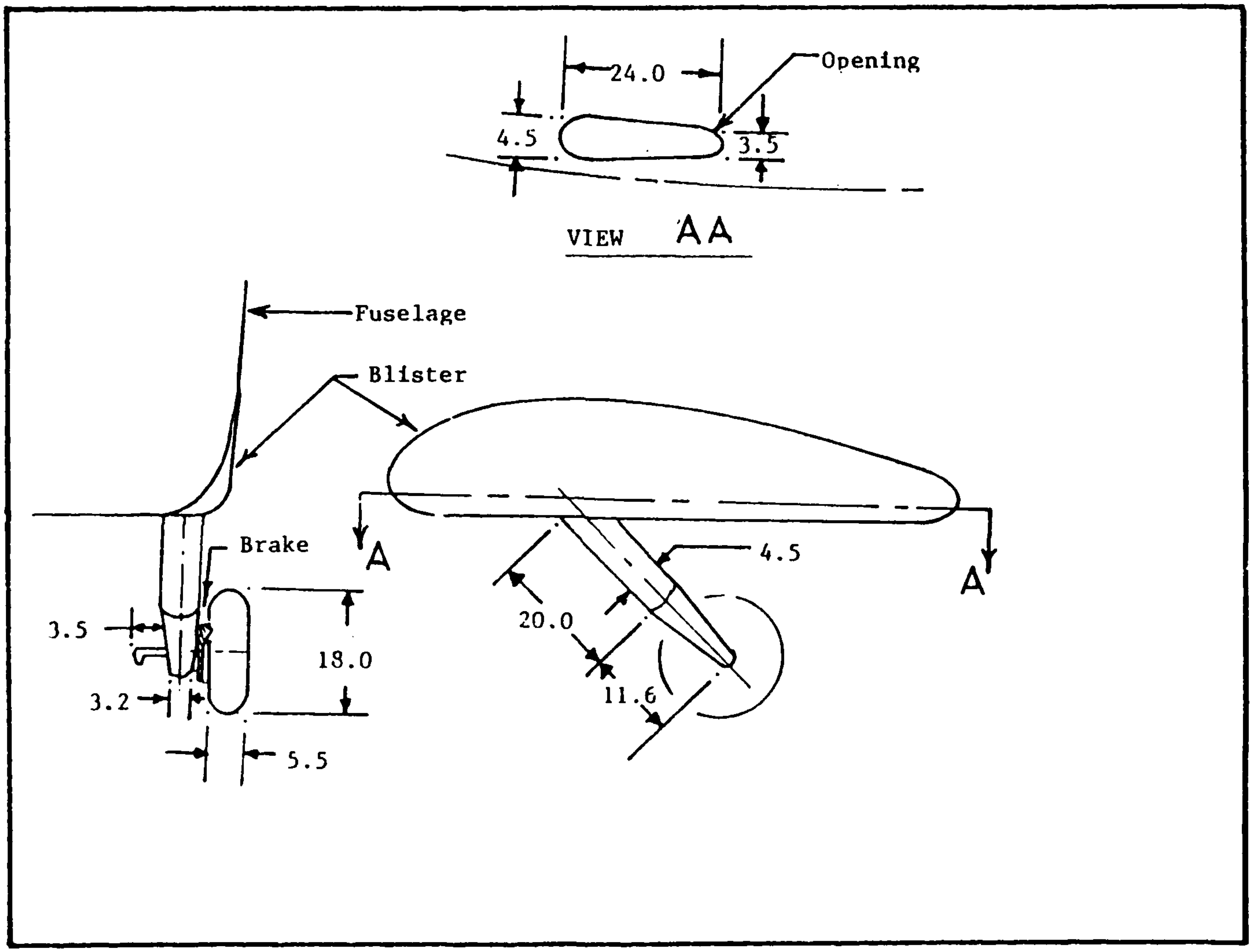


Figure 18. Configuration of fixed crashworthy main landing gear analyzed for drag.

TABLE 5. PARASITIC DRAG

Item	Drag Estimates, Δf, sq ft		
	Crashworthy		Standard
	Retractable	Fixed	Retractable
Total Helicopter			
• Retracted L.G.	10.16 (Faired)	-	9.39 (Flush)
• Extended L.G.	13.91	12.75	11.93
Landing Gear			
• Main	1.88	1.90	0.88
• Tail	0.53	0.44	0.44
• Fuselage/L.G. Gaps	1.00	-	1.00

3.9 GROUND RESONANCE ANALYSIS

Analytical evaluation of the ground resonance characteristics of the crashworthy landing gears was based on airframe mass and inertia properties shown in Table 6, landing gear stiffnesses, and kinematics of the BH1 baseline helicopter. The main gear tire properties are for a Type VII, 18.0 x 5.5, 12 PR with 67 to 150 percent of design pressure. The tail gear tire is of Type III, 5.00-4, 12 PR with 67 to 150 percent of design pressure. The rotor properties are scaled from a detailed design of HHI's Model 500 HARP hingeless rotor to the LHX geometry. The fundamental dimensions of the HARP rotor are given below.

GEOMETRY	500 HARP	LHX HARP
Rotor Radius, inch	164	222
Blade Chord, inch	10	16
Rotor Speed, rpm	497	361

TABLE 6. AIRFRAME MASS PROPERTIES

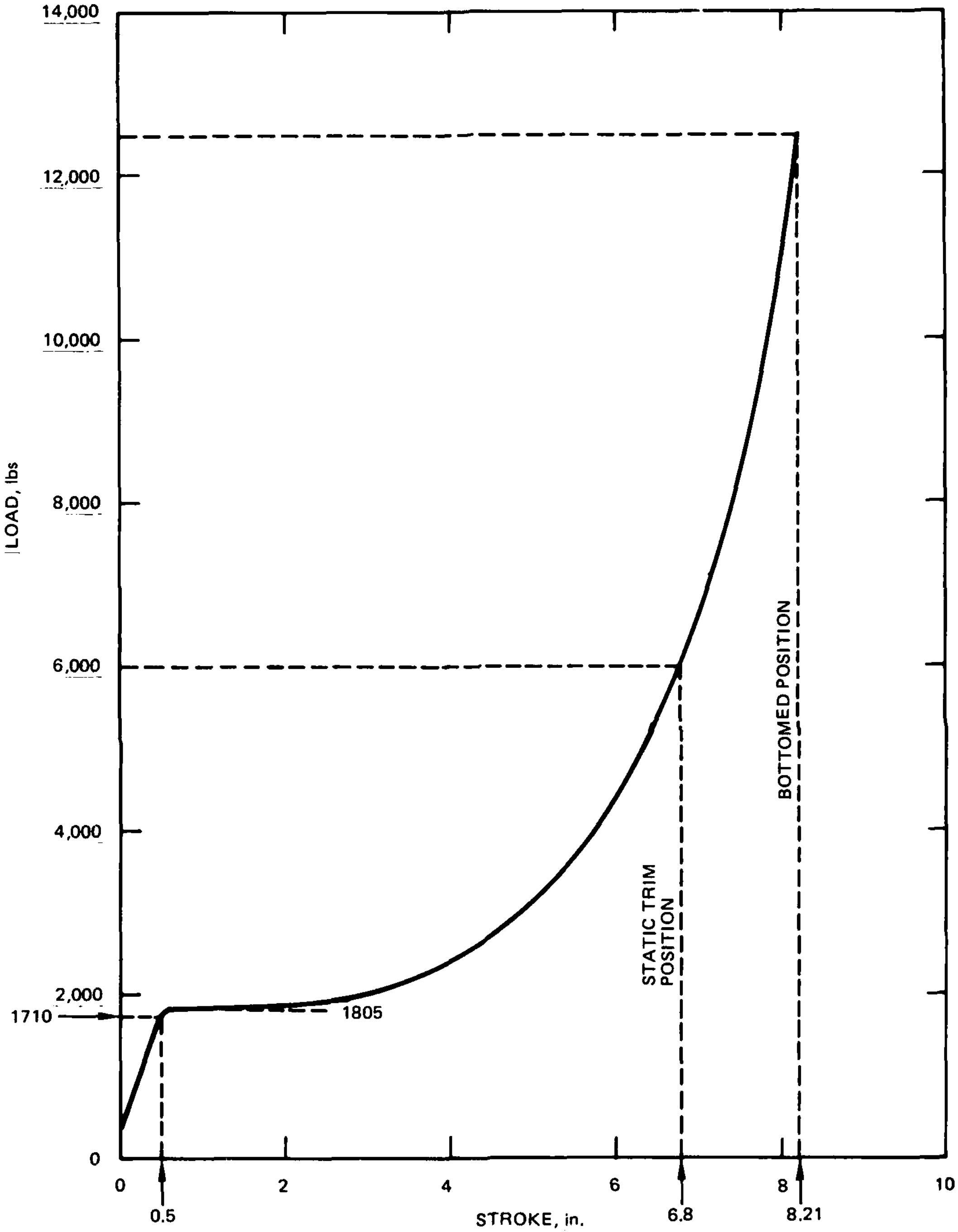
Item	Value
Gross Weight, lb	10,000
Vertical CG, in.	58.1
Horizontal CG, in.	205
Roll Inertia, 10^6 lb-in.^{2}	17.76
Pitch Inertia, 10^6 lb-in.^{2}	99.20
Yaw Inertia, 10^6 lb-in.^{2}	96.30

The main rotor properties are given in Table 7. The ground resonance analysis identified two requirements. The precharge of the main landing gear oleo should be 1710 lbs. This is shown in Figure 19. Specifications of an anti-extension spring to minimize the "dead-band" at lift-off are also shown in this figure. This is a conventional device used on most helicopter oleos.

It was also shown that an auxiliary orifice should be used in the oleo to increase damping at low velocities, associated with ground resonance, without affecting the damping forces during high velocities, associated with limit sink speeds and crash conditions. A similar auxiliary orifice is used in the oleo of the AH-64A Apache helicopter. The requirements of the auxiliary orifice are given in Figure 20.

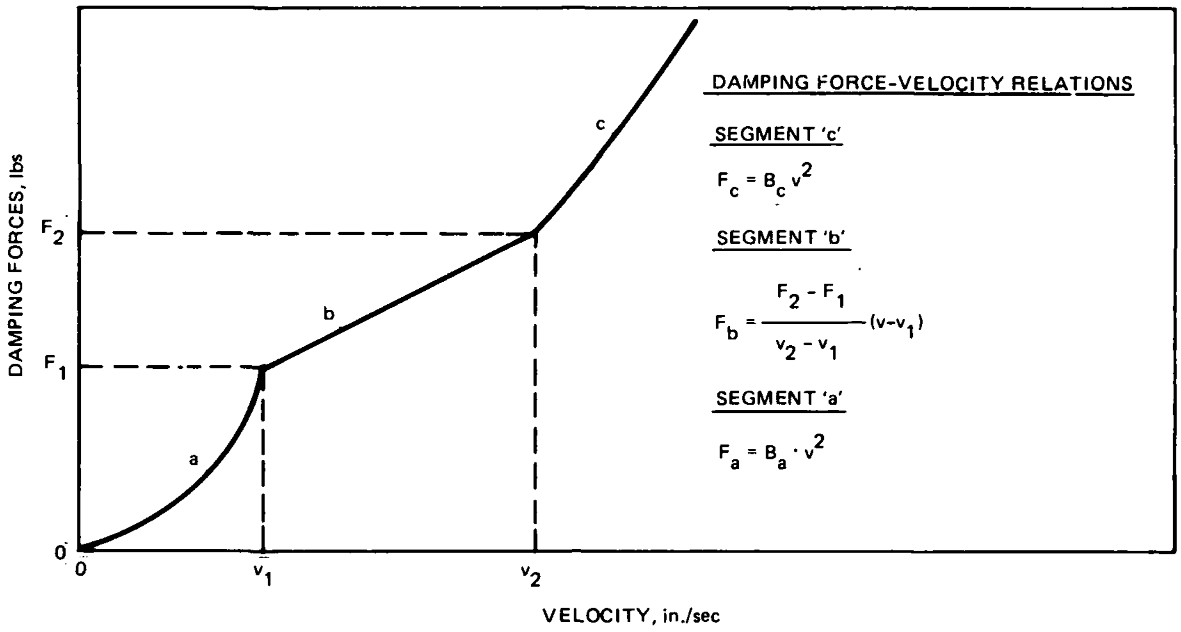
TABLE 7. MAIN ROTOR PROPERTIES

Item	Value
Lag Hinge Offset, in.	34.6
Weight Moment about Lag Hinge Station, in-lb	6,320
Moment of Inertia about Lag Hinge, lb-in^2	759,200
Lag Hinge Stiffness, in-lb/rad	130,700
Lag Hinge Damping, in-lb/rad	56,750



NOTE: THE OLEO CHARGE PRESSURE OF 1710 lbs. IS DETERMINED FROM THE INTERSECTION OF THE ANTI-EXTENSION SPRING STROKE (0.5 in.) WITH THE AIR CURVE

Figure 19. Oleo charge conditions for the crashworthy landing gear.



VARIABLE	COMPRESSION	EXTENSION
F_1	730	3360
F_2	1040	4030
v_1	2.5	5.36
v_2	12.5	10.71
B_a	117	117
B_c	6.67	35.1

Figure 20. Oleo damping requirements for the crashworthy landing gear.

These requirements have negligible effect on weight and add only a minor complexity to the oleo design. These features are incorporated into the designs of the crashworthy landing gears.

3.10 MATERIAL TRADE-OFF STUDY

Advanced material systems have been investigated for use in the landing gear components. The potential advantages of substituting advanced materials for conventional materials are

- Lighter weight
- Reduced volume and drag area

- Lower acquisition and life-cycle costs
- Applicability of design details.

The landing gear components which are potential candidates for redesign with advanced material systems are

- Torque tube or cross tube
- Trailing arm
- Shock strut

The advanced material component designs were studied as interchangeable units with components designed of the baseline material. Volume and size of the components are important criteria because of restrictions on increasing the drag area and the limitation of the available internal space.

The candidate components were selected for redesign with advanced material systems because design requirements indicated potential advantages. The choices of the various material systems for applicability to a given component were first weighted and ranked with respect to size, weight and cost. Following this evaluation, the requirements of detail design were given particular emphasis. Some of the areas which required definition were joints, bearing surfaces and attachment lugs which apply significant out-of-plane loads on the components. A preliminary evaluation of the anticipated advanced materials and processes is given in Table 8.

Metal matrix composites (MMC) are used where their high specific mechanical properties, low coefficient of thermal expansion, and stability of the mechanical properties at high temperatures can be best utilized. The aluminum matrix composites generally provide higher longitudinal strengths whereas titanium matrix composites provide higher transverse strengths and higher longitudinal stiffnesses, and are suitable for higher temperature applications. As with all fiber-reinforced materials, MMC can be tailored for a given application by varying the fiber, matrix, and fiber volume. An additional advantage of MMC is that conventional metal design considerations are generally applicable. The biggest drawback of these materials at this time, which reflects also on the design, is the poor potential for low-cost fabrication in large quantities.

In designing with organic composite materials, conventional design methods have to be reevaluated to achieve the potential of weight savings that these materials offer. Careful consideration must be given to joining techniques, methods of load transfer from and into composite structures, and impact damage from stones and debris to vulnerable areas of the landing gear. The advantages of organic composites are the very high specific strength and stiffness of the lamina, the ability to optimize the design by tailoring the constituent materials and by selectively using hybrids for specific requirements, and the ease of repairability.

3.10.1 Composite Materials for Coupled Landing Gear

After evaluating the properties of the materials listed in Table 8, the two materials selected for initial analysis were 6Al-4V titanium and graphite/epoxy composite because of low material cost and ease of fabrication. Titanium, with a very low torsional stiffness compared to steel and graphite, has no weight

TABLE 8. SUMMARY OF ADVANCED MATERIALS AND PROCESSES FOR HELICOPTER LANDING GEARS

PROPERTY AND/OR BEHAVIOR	ORGANIC MATRIX		ADVANCED PROCESS	METAL MATRIX			
	Gr/Ep (v_f = 0.6)	B/Ep (v_f = 0.5)	6-4-Ti SPF/DB	B/Al (v/o = 0.45)	Gr/Al (v/o = 0.3)	FP/Al (v/o = 0.3)	$B_4C(B)/Ti$ (v/o = 0.38)
SPECIFIC TENSILE (0°) STRENGTH, 10^6 LBF-IN/LBM	4.15	2.20	0.862	2.21	1.06	0.56	1.73
SPECIFIC ±45° SHEAR STRENGTH, 10^6 LBF-IN/LBM	0.70	–	0.51	0.95	0.53	0.28	–
SPECIFIC MODULUS (0°), 10^6 LBF-IN/LBM	301.89	414.67	100.0	326.32	235.29	229.51	246.15
COST, $/LB	40	200	25	500	1200	–	1500
FABRICATION OR MACHINING	SIMPLE	DIFFICULT	SIMPLE	DIFFICULT	SAME AS ALUMINUM	CASTING	DIFFICULT
RESISTANCE TO FOREIGN OBJECT DAMAGE	POOR	POOR	GOOD	POOR	POOR	POOR	GOOD

Legend for terms: v_f = fiber volume fraction, v/o = filament volume fraction

advantage for the torque tube or trailing arm because of the high torsional loads. A graphite/epoxy torque tube with a steel fitting was judged to be comparable in weight to a fully steel torque tube. The weights of five alternative materials for the components of the landing gear, sized on the basis of static loads are given in Table 9. The table includes weight comparisons for cases of bolted and bonded steel fittings, with a graphite/epoxy torque tube, along with titanium and steel baseline data.

The weights of the graphite/epoxy torque tube with steel fittings are comparable to those of the steel baseline torque tube on the basis of static loads. Trailing arm design with graphite/epoxy was not investigated because of the limitation of the available internal space for the retractable landing gear. In contrast, weights of the titanium torque tube and trailing arm assembly were 10 percent to 30 percent greater than the corresponding steel baseline.

Though graphite/epoxy material looked encouraging for use on the torque tube under static loading, it was rejected on the basis of dynamic load. The results of KRASH analysis identified the dynamic torsional load on the torque tube to be over 2,000,000 inch-pounds, more than double that of the 1,000,000 inch-pounds used for the static load to initially size the component. Since the outer diameter of the torque tube remains constant, increasing the wall thickness of the tube internally to react the increased torsional load will result in quickly reaching the point of diminishing returns. The weights of the steel baseline and graphite/epoxy torque tubes for the increased dynamic loads are shown in Table 10. The graphite/epoxy torque tube is more than 10 percent heavier than the steel baseline.

As explained in Section 3.3, a combination actuator and energy-absorbing strut, together with a simply articulated gear, was chosen for a lightweight design of the landing gear because dedicated actuators for retraction and kneeling are not required. This combination oleo/shock strut, with efficiencies as high as 90 percent, is almost the perfect device for absorbing the kinetic energy due to sink speed (Reference 6). The close tolerances required on the elements of the oleo/pneumatic shock absorbers to achieve the high efficiency level, and the labor-intensive design of such an absorber, does not lend itself to redesign with composite materials.

The conventional 300M alloy steel was, therefore, chosen for the designs of all the landing gears with coupled trailing arms.

3.10.2 Composite Materials for Uncoupled Landing Gear

From the analysis on the torque tube, it was apparent that the cross tube for the uncoupled landing gear lends itself to composite materials. With bending moment rather than torsional load the driving criterion, the cross tube was redesigned with graphite/epoxy with steel end-fittings to provide the bearing surfaces required for mounting the trailing arms. The end-fittings are shown bonded on to the graphite/epoxy cross tube in Figure 21. The redesigned cross tube weighs 24 pounds to react the loads of the most severe crash impact condition of 42 fps at 15-degree roll and 0 degree pitch. The graphite/epoxy cross tube is 19 pounds lighter than the steel cross tube. The weight breakdown of uncoupled landing gears with graphite/epoxy and steel cross tubes are given in Table 11.

TABLE 9. MATERIAL TRADE-OFF STUDY FOR LANDING GEAR COMPONENTS, STATIC LOADS

COMPONENT	WEIGHT IN POUNDS				
	STEEL BASELINE	Gr./Ep. TORQUE TUBE			Al–4V TITANIUM SPF/DB
		STEEL FITTING		6 AL–4V Ti FITTING, BOLTED	
		BOLTED	BONDED		
TORQUE TUBE ASSY	99.87	100.92	100.77	107.46	109.74
● TORQUE TUBE	● 39.65	● 31.80	● 31.80	● 31.80	● 43.85
● FITTINGS	● 60.22	● 69.12	● 68.97	● 75.66	● 65.89
TRAILING ARM ASSY	59.20	–	–	–	81.70

TABLE 10. MATERIAL TRADE-OFF STUDY FOR TORQUE TUBE, DYNAMIC LOADS

COMPONENT	WEIGHT IN POUNDS		
	STEEL BASELINE	Gr./Ep. TORQUE TUBE	
		STEEL FITTING	
		BOLTED	BONDED
TORQUE TUBE ASSY	163.72	180.37	180.22
● TORQUE TUBE	● 103.50	● 111.25	● 111.25
● FITTINGS	● 60.22	● 69.12	● 68.97

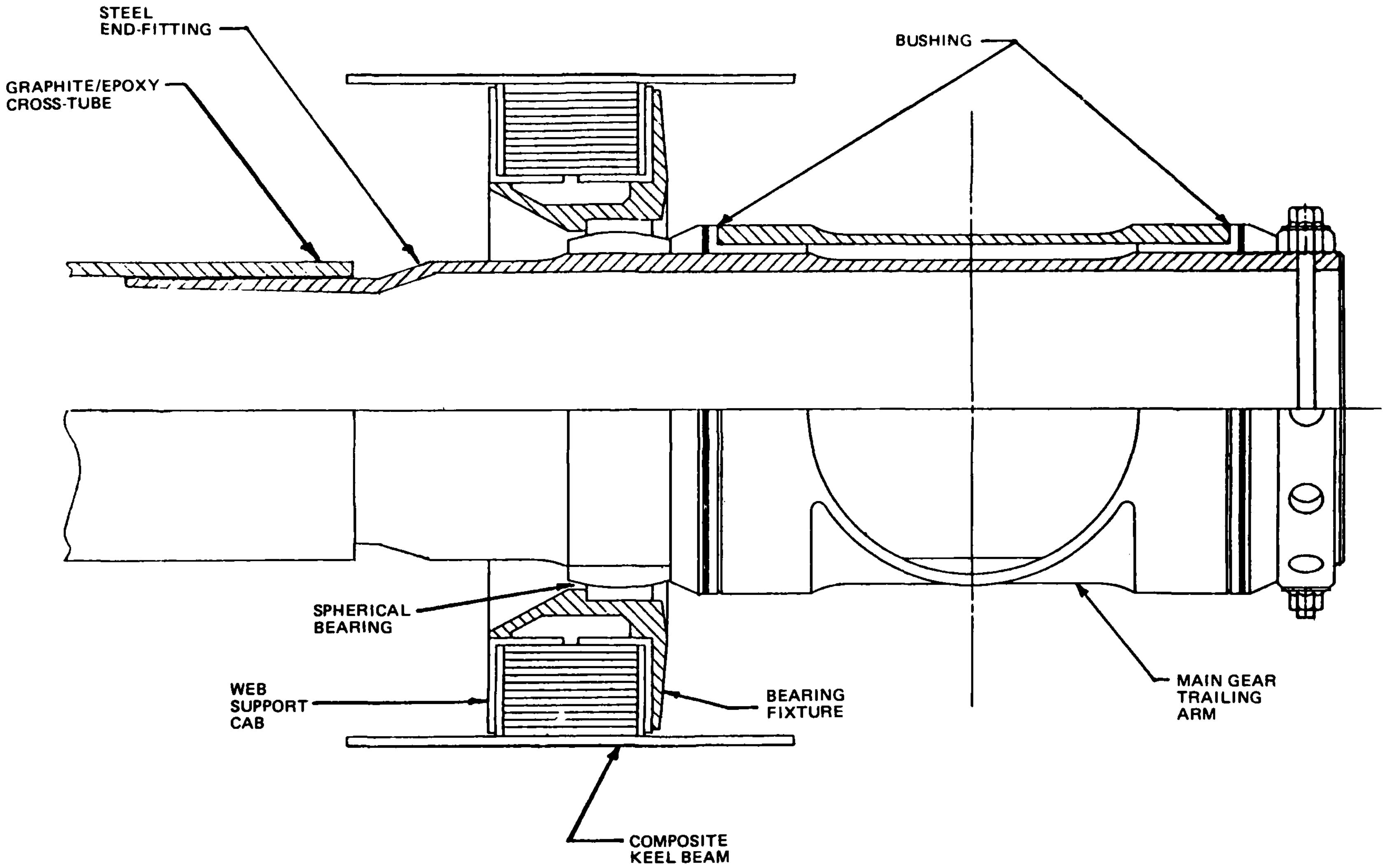


Figure 21. Assembly of graphite/epoxy cross tube and steel trailing arm of crashworthy uncoupled landing gear.

TABLE 11. WEIGHTS OF UNCOUPLED LANDING GEAR COMPONENTS WITH STEEL AND COMPOSITE CROSS TUBES

Component	Weights of Landing Gear with Steel Cross-Tube				Weights of Landing Gear with Graphite/Epoxy Cross Tube			
	Retractable		Fixed		Retractable		Fixed	
	MLG	TLG	MLG	TLG	MLG	TLG	MLG	TLG
Rolling Assembly	68	10	68	10	68	10	68	10
Cross Tube	43	-	43	-	24	-	24	-
Gear-Fuselage Attach. Ftgs	15	10	15	10	15	10	15	10
Trailing Arms	52	22	52	29	52	22	52	29
Shock Strut	128	20	117	12	128	20	117	12
Attachment Fittings	12	5	12	5	12	5	12	5
Controls	26	3	-	-	26	3	-	-
Subtotals	344	70	307	66	325	70	288	66
Totals	414		373		395		354	

NOTE: The weights shown for crashworthy landing gears are for the greatest impact condition.

SECTION 4

'KRASH' ANALYSIS WITH COUPLED LANDING GEAR

4.1 SYSTEMS APPROACH TO CRASHWORTHINESS

A survivable impact implies that, for a particular crash condition, the crew will not be incapacitated by injuries. A crashworthy helicopter design protects the crew by considering the many criteria affecting the crew environment. Two paramount design considerations are

- Providing a protective structural shell around the occupants that will not collapse or allow heavy mass items to penetrate into the occupied space

- Minimizing the effect of the crash impulse on the crew

To design efficiently and effectively to meet these requirements, a systems approach to crashworthiness has been adopted.

For severe, yet survivable, impacts the system of energy absorption consists of three elements: the landing gear, the crushable floor structure, and the load-attenuating crew seat. This has been illustrated in Figure 3. To develop a well-balanced and consistent design approach, any one particular element is not considered to be more important than any of the other two in providing crash protection. Instead, a systems approach is adopted in which each element is considered an integral link in the chain of energy absorption, where each link is as important as the rest and the whole system provides the desired protection for the crew.

The results presented for impacts of the crashworthy retractable landing gear in the extended position also apply to the crashworthy fixed landing gear. The two designs are identical except that the fixed gear is 41 pounds lighter due to the elimination of the retraction mechanism as discussed in Section 3.4.

4.2 CRASHWORTHINESS DESIGN PARAMETERS

The analytical approach used to verify the crashworthy design features is program KRASH (Reference 1). During the preliminary design effort, a simple five-mass KRASH model was created. The simple model, shown in Figure 22, was used for initial iterations to assess the system size and crew survivability requirements before finalizing the preliminary design. The proposed landing gear design utilizes a tailwheel helicopter configuration, where nearly 75 percent

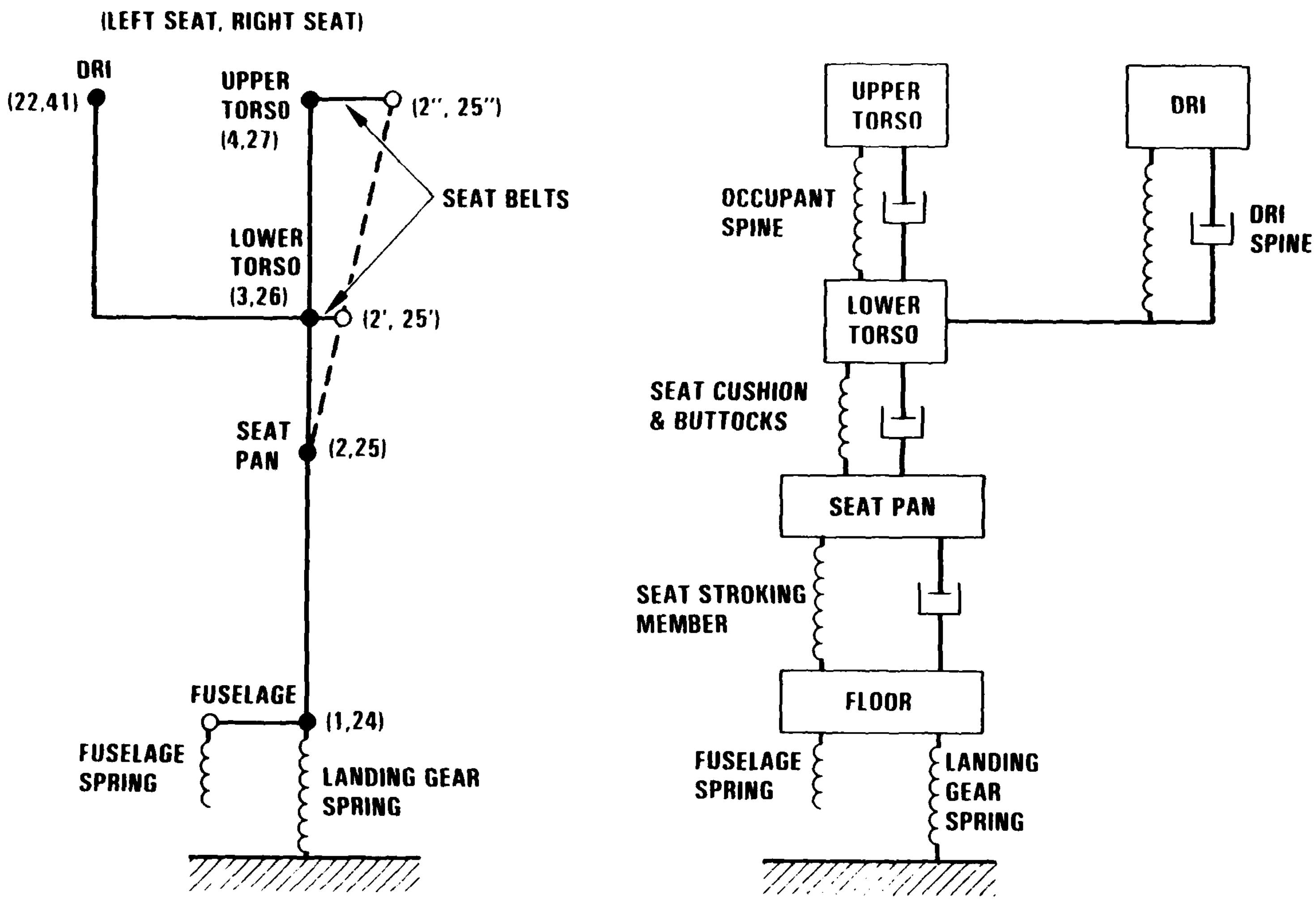


Figure 22. Simple and occupant 'KRASH' model.

of the helicopter weight is supported by the main landing gear. Since the main landing gear is located in close proximity to the crew cabin, the simple KRASH model represents only that portion of the aircraft supported by, and in close proximity to, the main landing gear.

The simple KRASH model represents the main landing gear as a spring which supports an occupant and a seat, and the distributed mass of the helicopter. Also modeled is the crushable fuselage under the crew compartment, the energy-absorbing crew seat and the Dynamic Response Index (DRI) of the occupants. The results from this model were used to verify the initial calculations made to size the system and to optimize the size requirements for the particular design constraints.

The DRI is a model of spinal injury and is used to predict the maximum deformation of the spine and the associated force within the vertebral column for various short-duration accelerations (Reference 7). An analytical relationship exists relating DRI to the injuries experienced. The higher the DRI-value, the greater is the injury. A DRI of 21 is considered to be within acceptable human tolerance levels (Reference 8).

As a result of the study with the simple model, three configurations of landing gear, fuselage and crew seat were chosen as possible design solutions in a trade-off study with other design constraints such as braking, turning, passenger or cargo loading and transportability. Table 12 summarizes the results for these configurations.

Using the occupant response (DRI) as a measure of the severity of an impact, the results of all these configurations indicate the impacts are survivable. It was decided to focus the design around the 7g landing gear because the DRI for that impact condition was considered the most acceptable compromise of the cases. Overprotection, or low DRIs, would probably result in weight increases, and the higher DRI (20.9) was considered borderline from the standpoint of the probability of an "acceptable" injury.

TABLE 12. CONFIGURATION STUDY TO OPTIMIZE SYSTEM SIZE REQUIREMENTS

The results are for a 42 fps vertical velocity and 0 degree roll and pitch

Configuration	Landing Gear		Fuselage		Crew Seat		DRI
	Load Factor, G	Stroke,* inches	Load Factor, G	Stroke, inches	Load Factor, G	Stroke, inches	
1	6.5	30	16	5.2	13.5	12.2	14.8
2	7.0	28	16	5.2	13.5	11.5	16.5
3	8.5	24	16	4.5	13.5	8.8	20.9

*Landing gear strokes represent the maximum at the time of fuselage contact.

With the model parameters now directed toward a more specific goal, detailed symmetrical and nonsymmetrical KRASH models were generated. The models are shown in Figure 23. The details of the crew seat portion of the model have already been shown separately in Figure 22. The models consisted of a 7g landing gear with 28 inches of stroke, a 16g fuselage with 7 inches of effective stroke, and a 13.5g crewseat with 14 inches of stroke.

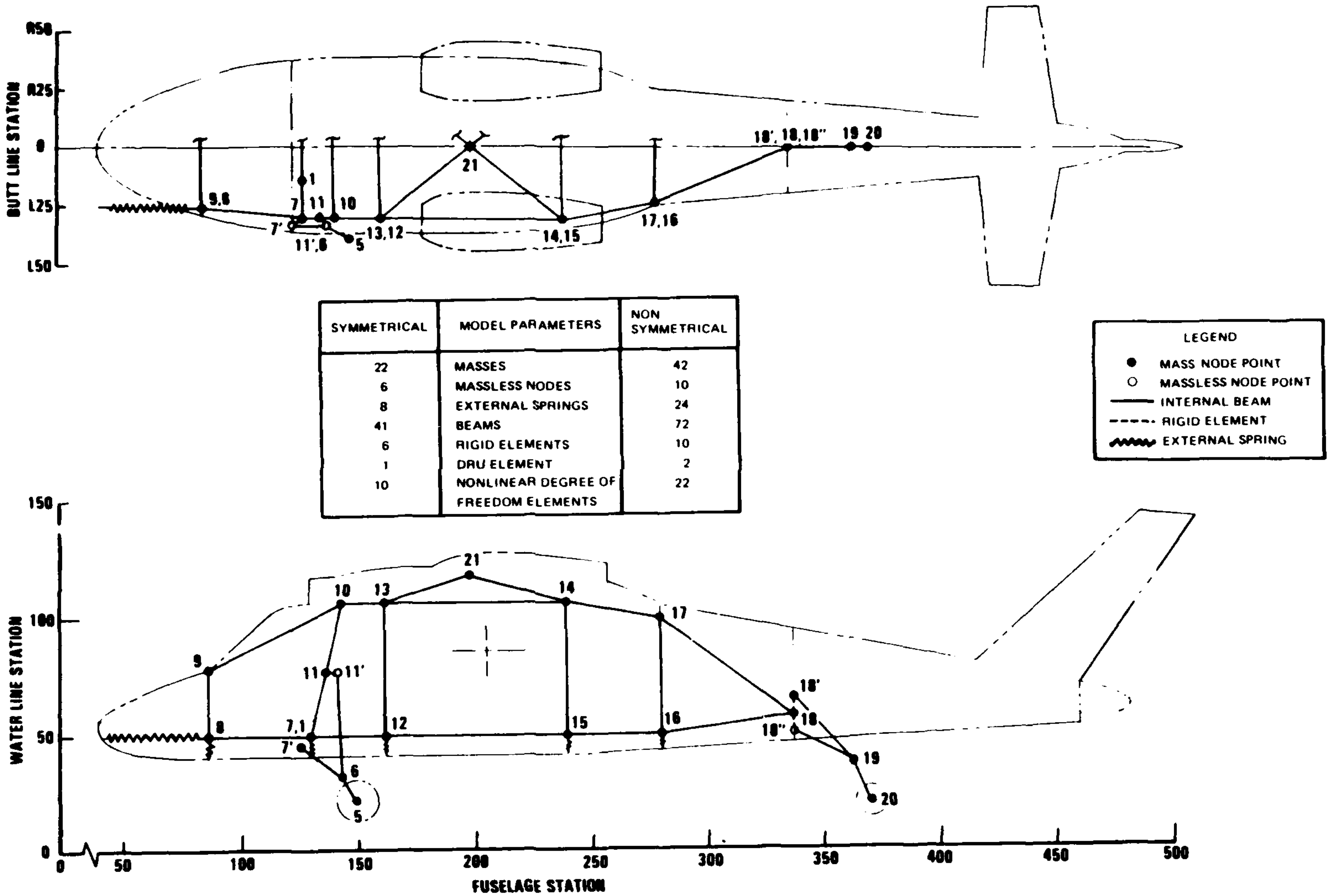
The preliminary analysis with this KRASH model was conducted for a 42 fps sink speed at impact attitudes of 0 degree roll and 0 degree pitch. It was found that the impact velocity of the fuselage resulted in fuselage deformations higher than those anticipated and, in some locations, exceeded the designed crushable distance. It was then decided to increase the load level of the landing gear to 7.5g. The subsequent KRASH analysis gave satisfactory results and the 7.5g load level was incorporated into the design. To utilize more of the underfloor crushable space, the load level of the crushable floor structure was lowered from 16g to 15g. The resulting design accelerations for vertical impacts are shown in Figure 24.

4.3 PHASE I KRASH ANALYSIS

Phase I analysis of crash impact behavior was initiated with the KRASH model modified to reflect the new load levels. The symmetrical and nonsymmetrical impact conditions analyzed are shown in Figures 25 and 26. The combined symmetrical and nonsymmetrical KRASH analyses comprise 26 impact conditions.

All the impact conditions studied were survivable as evidenced by the occupants' DRI data and by comparing the accelerations of the occupant seatpan, lower torso, and upper torso with the acceptable human tolerance limits given by the Eiband human tolerance curves (Reference 8). All of the inputs tested are considered successful using the occupant response as the indicator of a survivable impact.

The simulated landing gear design functioned as expected and absorbed the necessary energy needed to attenuate the impact velocities to levels that could be absorbed successfully by the fuselage. For severe vertical impacts of 42 fps, the landing gear absorbs nearly 52 percent of the impact kinetic energy. The landing gear efficiency was assumed to be 80-85 percent, similar to that of the AH-64 helicopter. The strokes of the main and tail landing gear versus sink speed and aircraft impact attitude are shown in Figures 27 and 28 for symmetrical impact and in Figures 29 through 31 for nonsymmetrical impact. The longest landing gear stroke is required at 42 fps sink speed with 10 degrees roll and -5 degrees pitch for the main gear and with 5 degrees roll and +15 degrees pitch for the tail gear. The advantage of designing the main landing gear with torque tube coupling is shown in Figure 32. Without torque-tube coupling, the stroke requirements of the main landing gear are 67 percent greater for the severest case of 42 fps sink speed, 20 degrees roll and +15 degrees pitch. It was found that the stroke requirements for the fuselage and crew seats were also considerably lower with torque tube coupling.



SYMMETRICAL	MODEL PARAMETERS	NON SYMMETRICAL
22	MASSES	42
6	MASSLESS NODES	10
8	EXTERNAL SPRINGS	24
41	BEAMS	72
6	RIGID ELEMENTS	10
1	DRU ELEMENT	2
10	NONLINEAR DEGREE OF FREEDOM ELEMENTS	22

Figure 23. Phase I symmetrical and nonsymmetrical 'KRASH' models.

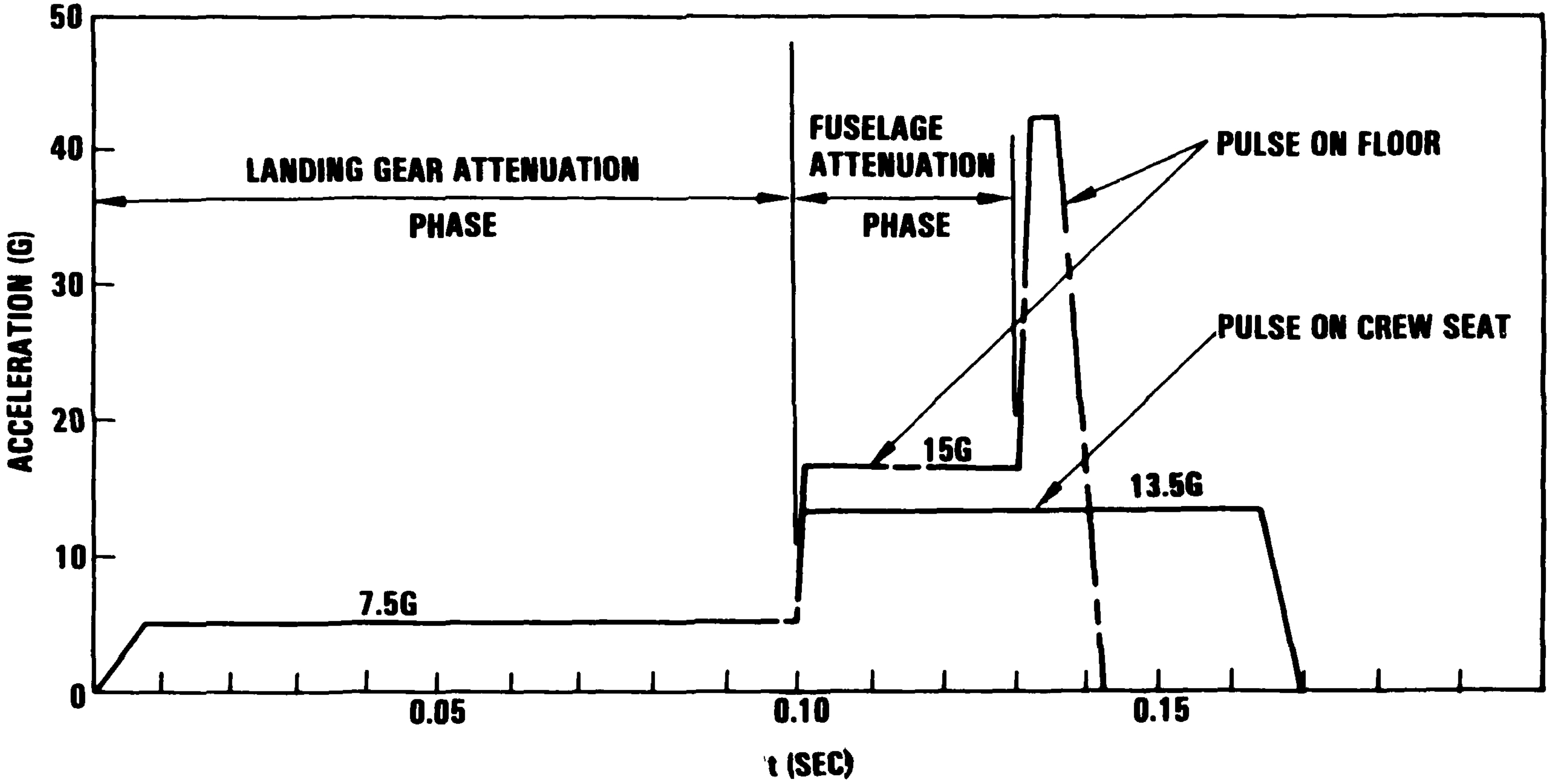


Figure 24. Design accelerations for severe vertical impacts for Phase I study.

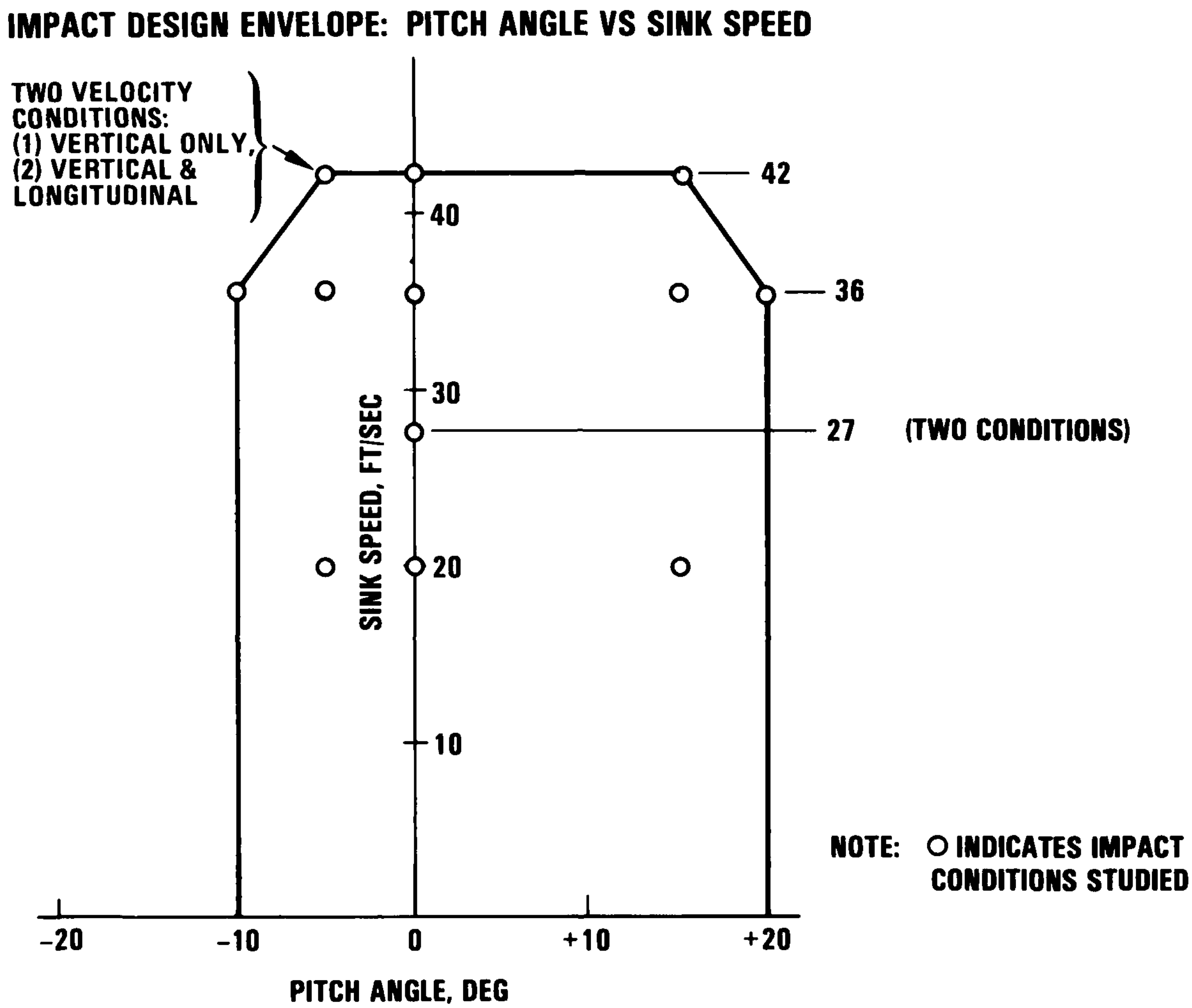


Figure 25. Symmetrical impact conditions analyzed in Phase I study.

IMPACT DESIGN ENVELOPE: PITCH & ROLL ANGLE VS SINK SPEED

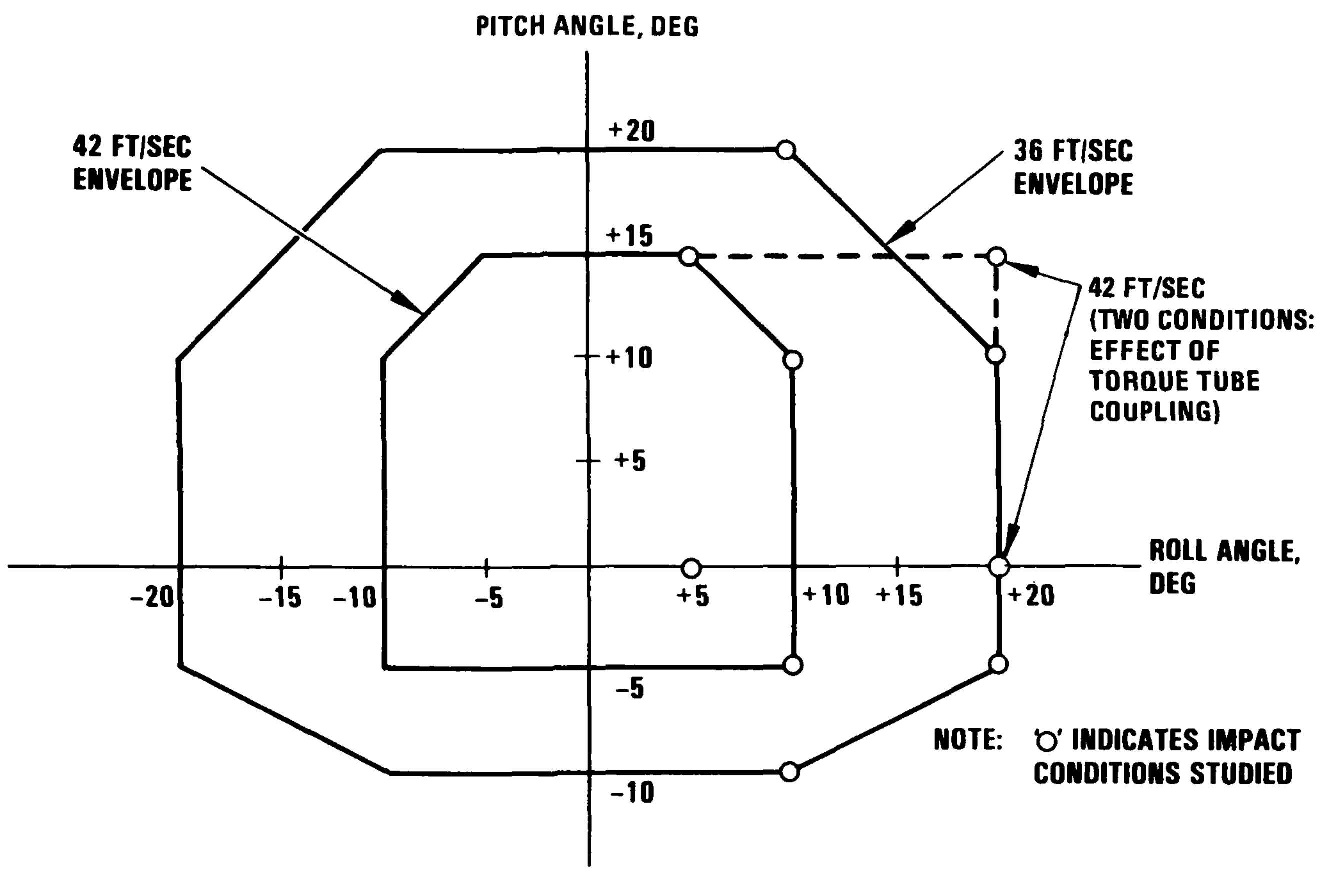


Figure 26. Nonsymmetrical impact conditions analyzed in Phase I study.

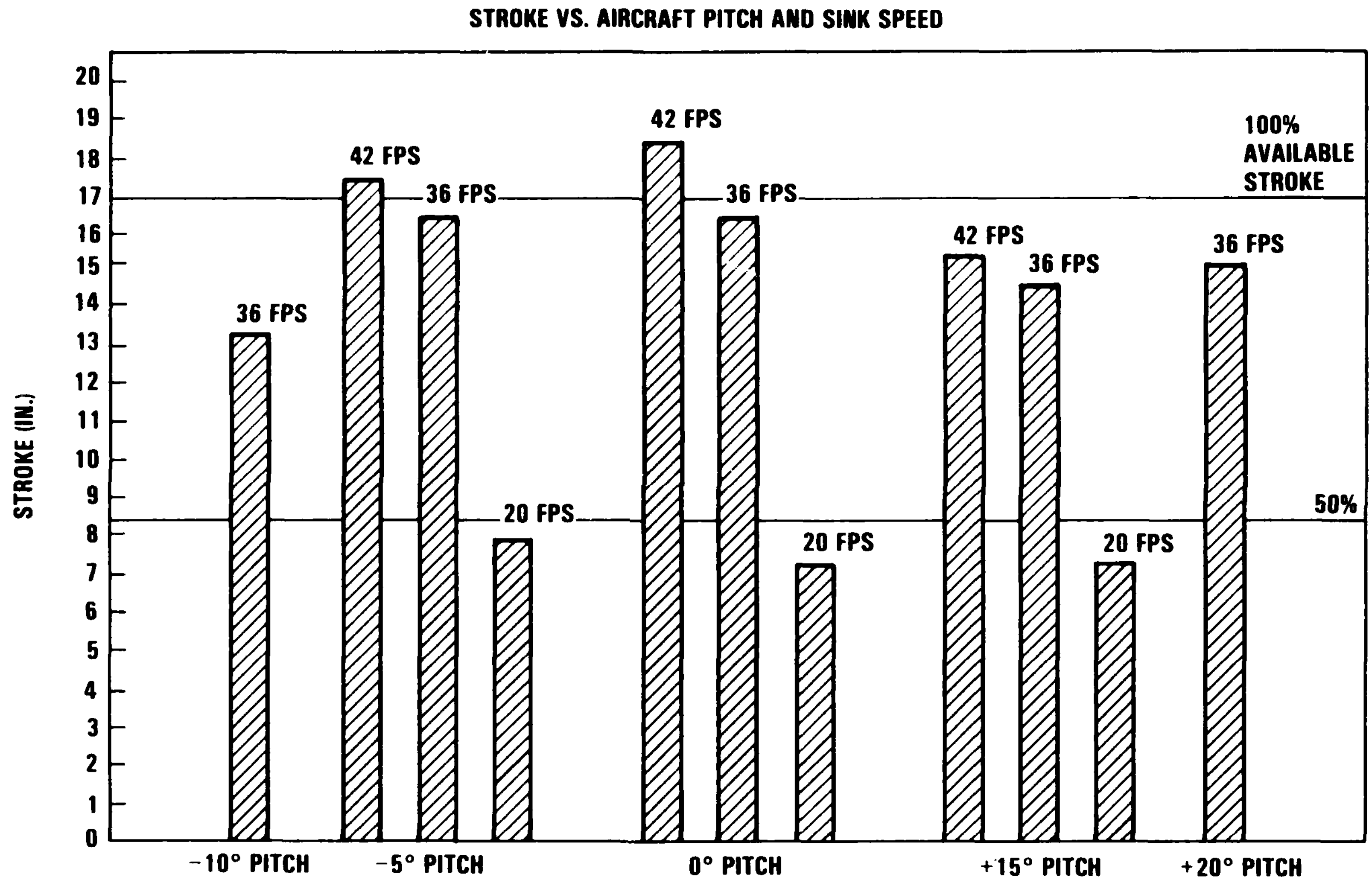


Figure 27. Coupled main landing gear strokes for symmetrical impact in Phase I study.

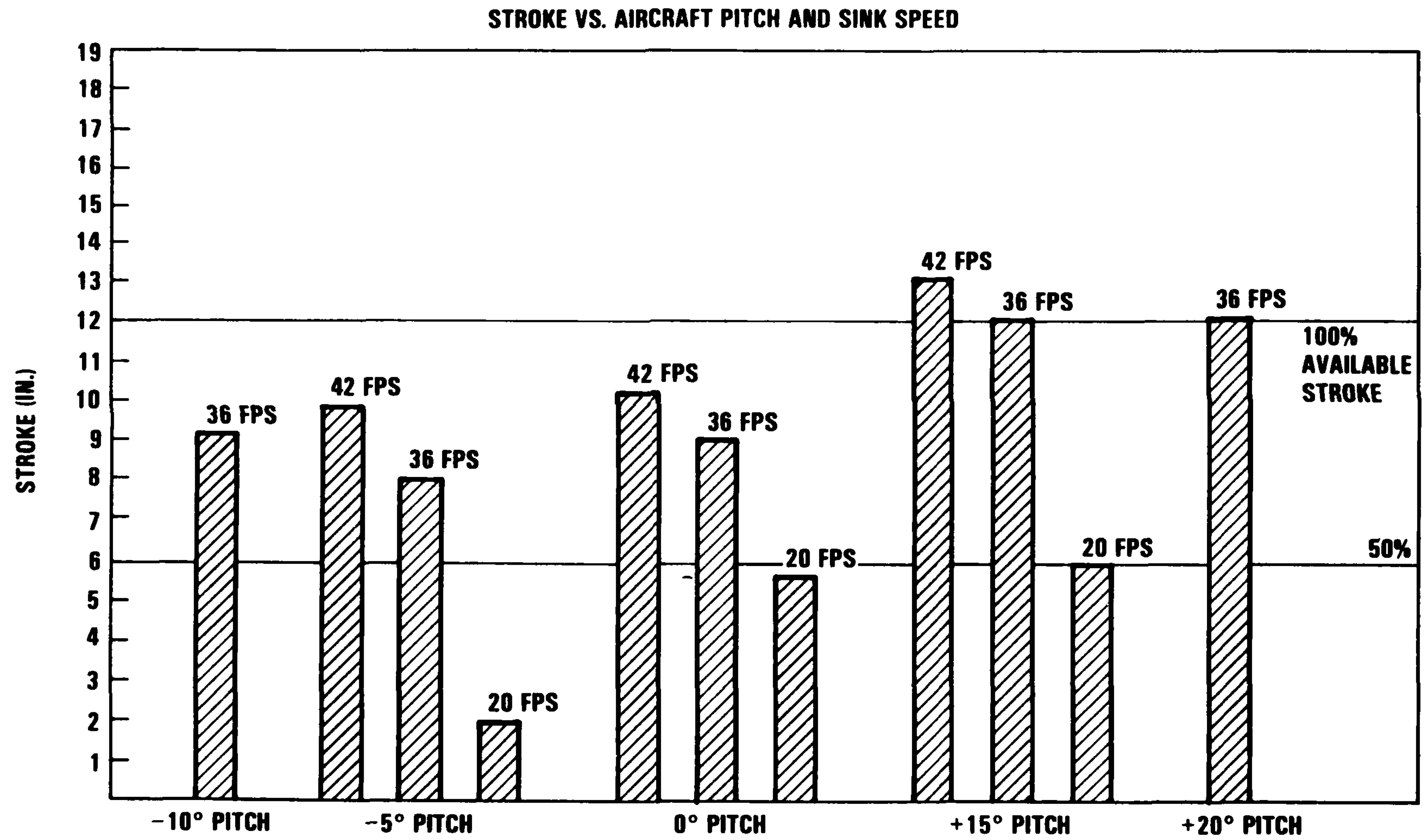


Figure 28. Tail landing gear strokes for symmetrical impact in Phase I study.

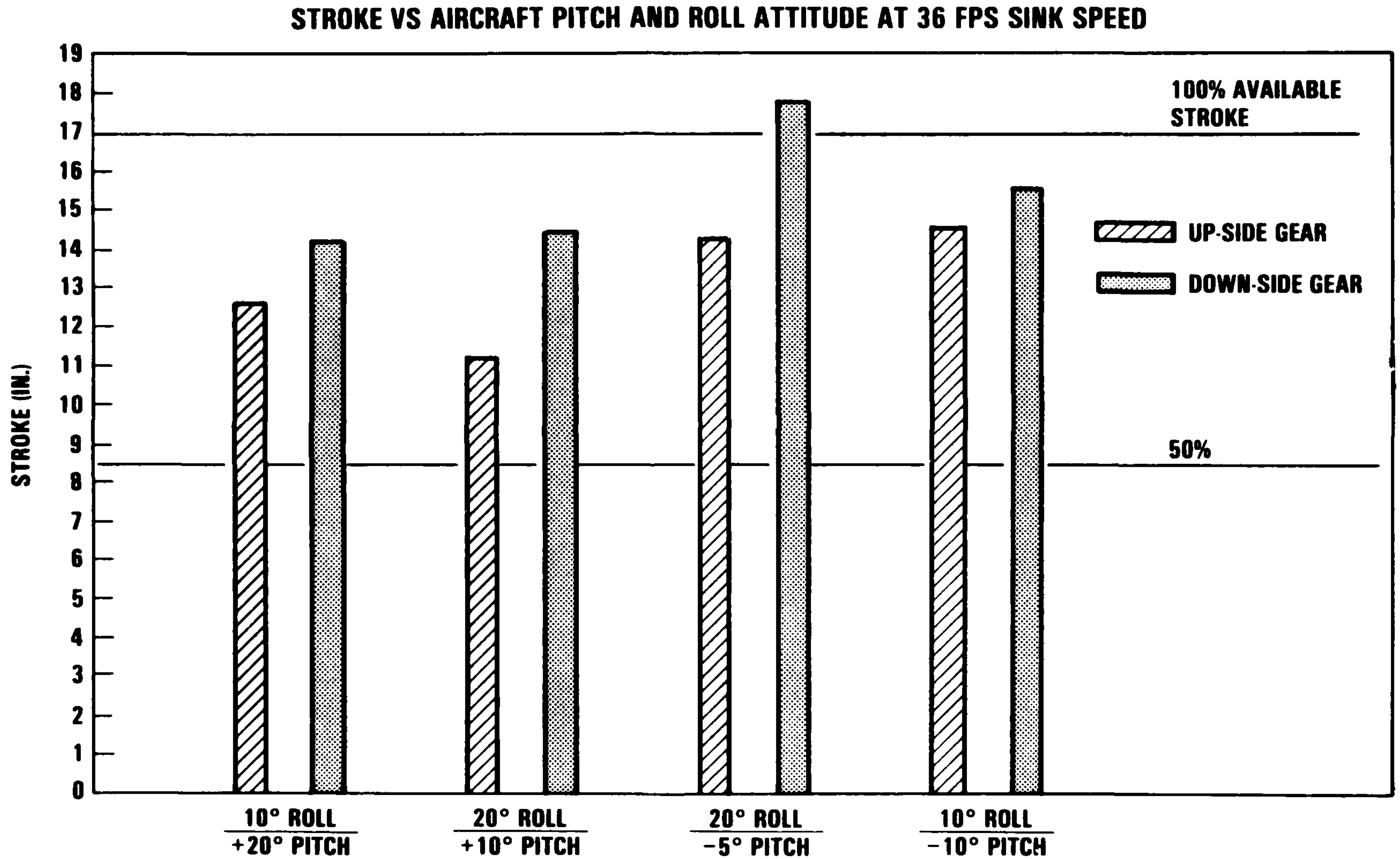


Figure 29. Coupled main landing gear strokes for nonsymmetrical impact at 36 fps sink speed in Phase I study.

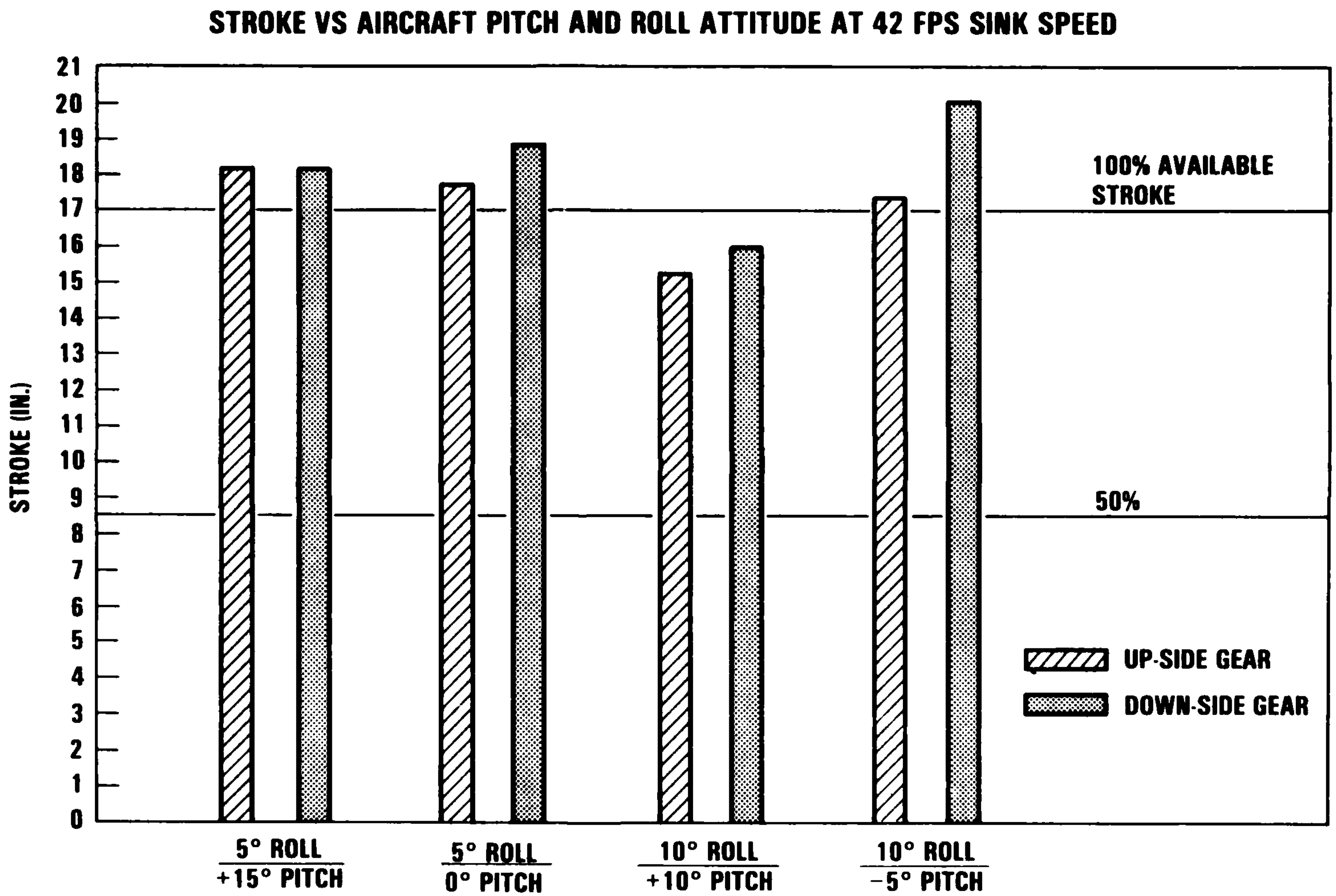


Figure 30. Coupled main landing gear strokes for nonsymmetrical impact at 42 fps sink speed in Phase I study.

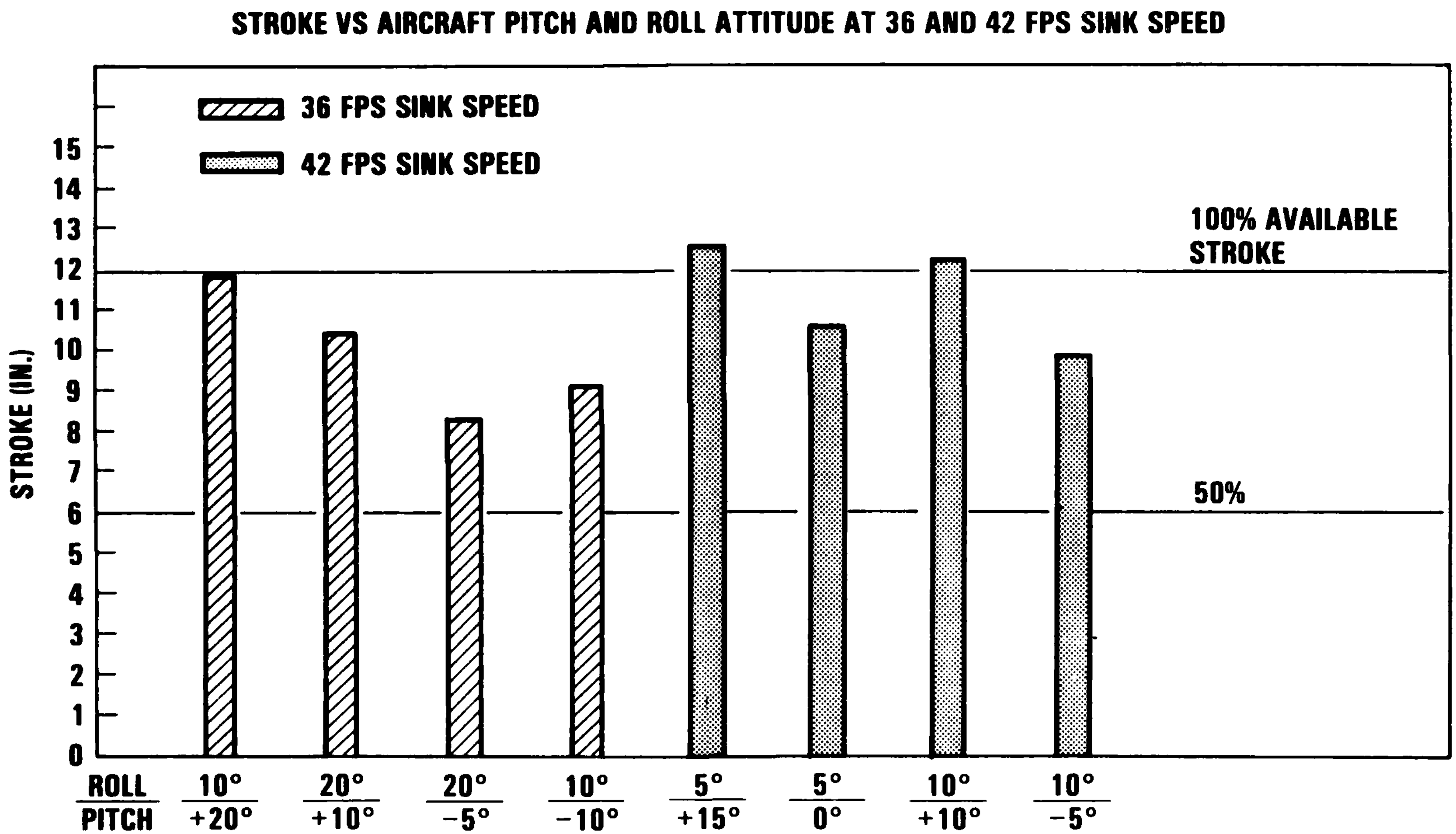


Figure 31. Tail landing gear stroke for nonsymmetrical impact at 36 and 42 fps sink speeds in Phase I study.

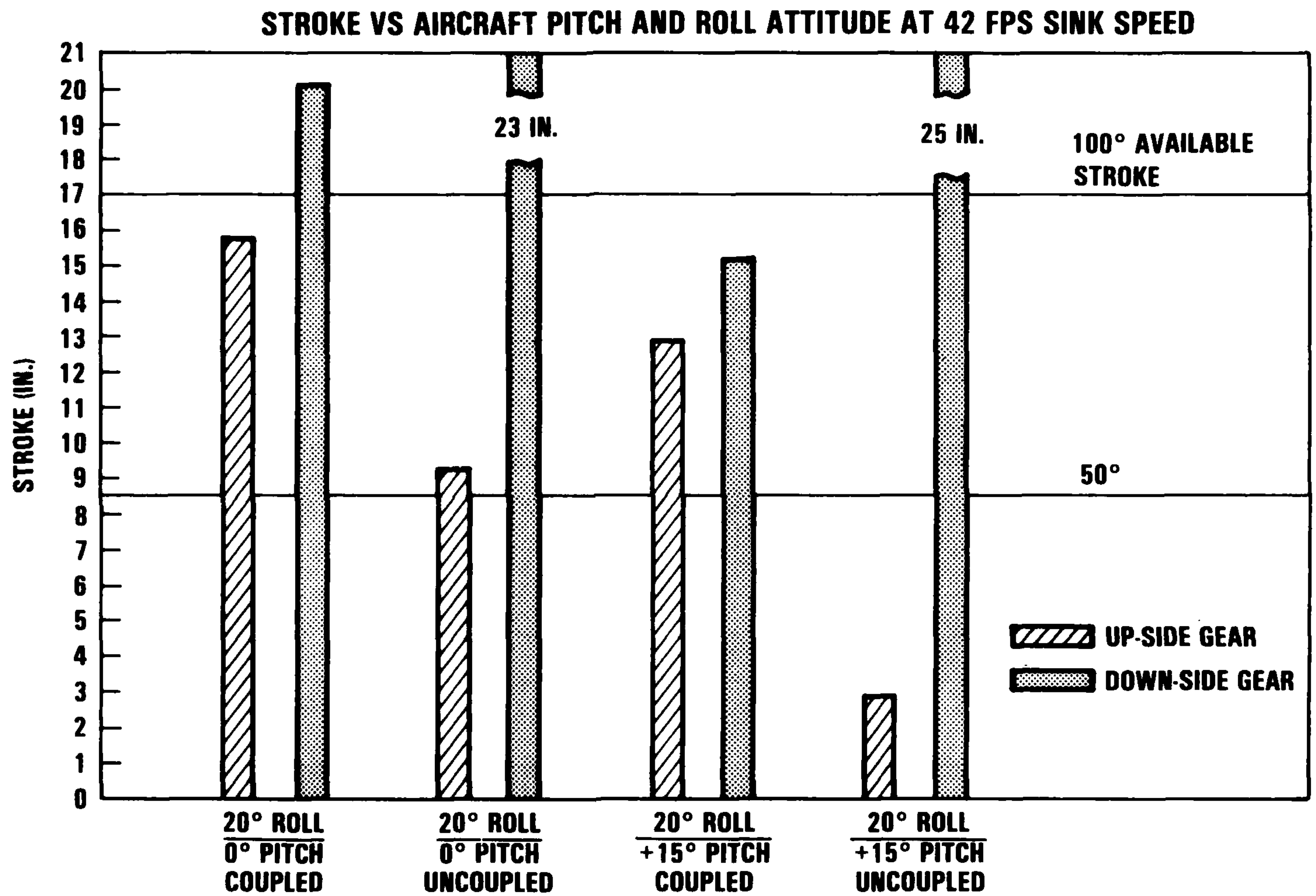


Figure 32. Main landing gear stroke with and without torque tube coupling for nonsymmetrical impact at 42 fps sink speed in Phase I study.

The fuselage deformations at 36 and 42 fps for symmetrical impacts are shown in Figures 33 and 34, respectively, and for nonsymmetrical impacts in Figures 35 and 36, respectively. In all cases the impacts were survivable. The most severe fuselage deformation occurred for impact conditions of 42 fps sink speed at 0 degree roll and -5 degrees pitch. The total designed crushable distance in the nose region of the aircraft was utilized. With the fuselage bottoming out, the fuselage crushing stiffness is greatly increased and large loads can occur for very short additional strokes, which increase the possibility of transmitting injurious accelerations to the occupants. In the present design, however, sufficient residual stroke in the crew seat is present to attenuate these higher load levels when the fuselage bottoms out.

The seat strokes for symmetrical crash impacts and the corresponding DRIs are given in Figures 37 and 38. The DRI values ranged from 16.1 to 19.8, which correspond to acceleration levels in the no-injury area of the Eiband human tolerance curve shown in Figure 39. The severe deformation in the fuselage nose at 42 fps sink speed, 0 degree roll and -5 degrees pitch, as discussed earlier, resulted in maximum stroking of the crew seat. The DRI (19.3) and the upper and lower torso accelerations of the occupant indicate little possibility of occupant injury.

Two additional symmetrical KRASH analyses were conducted with gear-up condition at 27 fps with and without residual energy capability. Honeycomb, similar to those in the keel beam, was designed into the fairings above the retracted gear to provide the residual energy capability. The energy-absorbing fairing reduces deformation in the forward and mid sections of the fuselage by 25 to 7 percent, as seen in Figure 34, and requires slightly longer crew seat stroke, as seen in Figure 37. However, the occupant response, in general, are equivalent for both these conditions as seen in Figures 38 and 39.

The seat strokes for nonsymmetrical impacts were all below the available design seat stroke (Figure 40). The corresponding DRIs, shown in Figure 41, ranged from 17.5 to 19.9, and the accelerations of the upper and lower torsos indicate no injurious loads are transmitted to the crew as demonstrated on the Eiband curve, shown in Figure 42. The DRIs predicted by program KRASH are consistent with the peak DRI calculated with a trapezoidal seat pulse. This correlation is shown in Figure 43.

The effect of torque-tube coupling on landing gear stroke for nonsymmetrical impacts at 42 fps was discussed earlier and illustrated in Figure 32. The 67 percent increase in landing gear stroke for the uncoupled case (20 degree roll and +15 degree pitch) also resulted in 62.5 percent increase in crew seat stroke. In contrast, for 20 degree roll and 0 degree pitch, whereas the uncoupled landing gear stroke increased by 15 percent, the crew seat stroke for the uncoupled case increased 315 percent. The seat strokes with and without torque tube are shown in Figure 44.

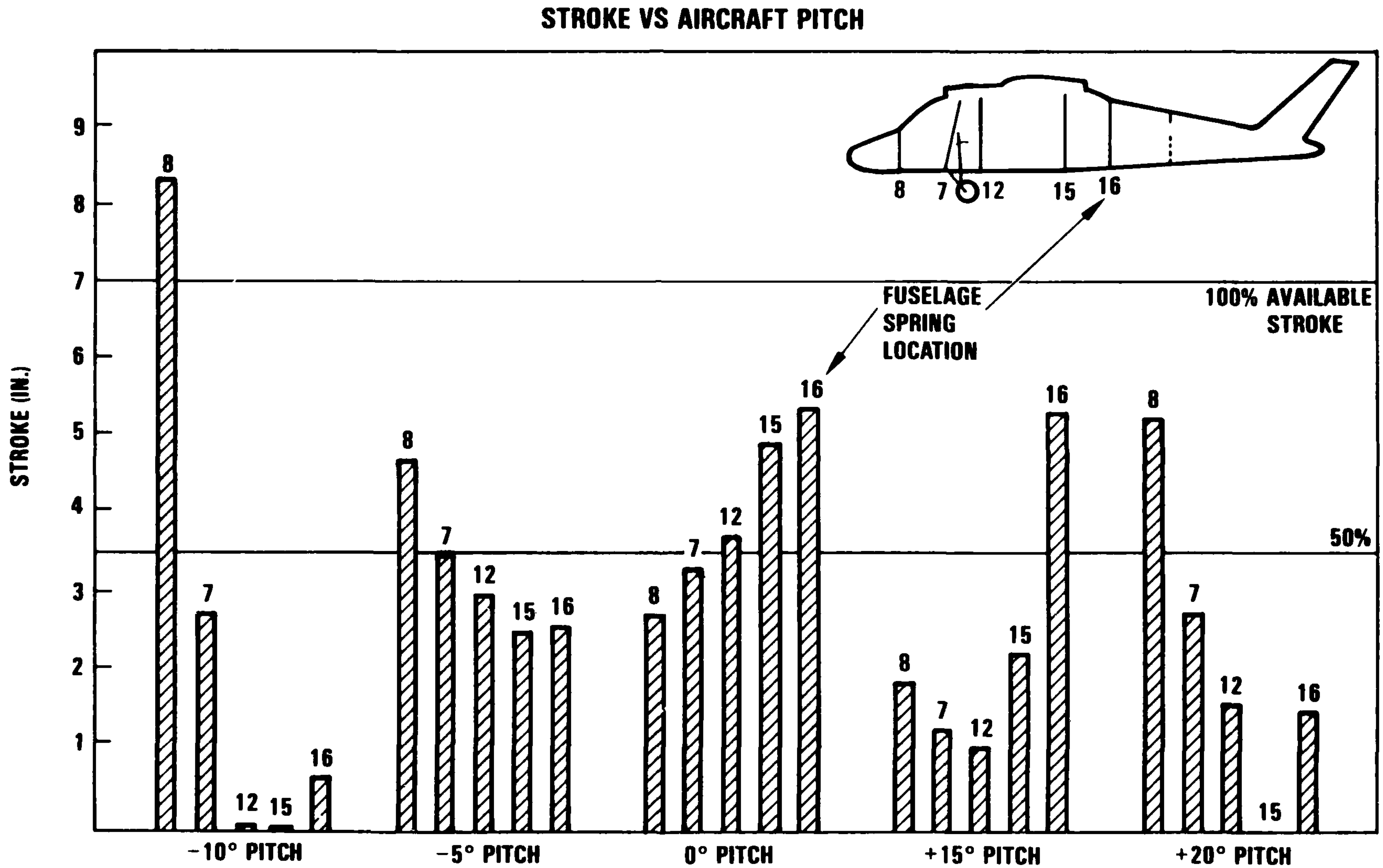


Figure 33. Fuselage subfloor crushing for symmetrical impact at 36 fps sink speed in Phase I study of coupled landing gear.

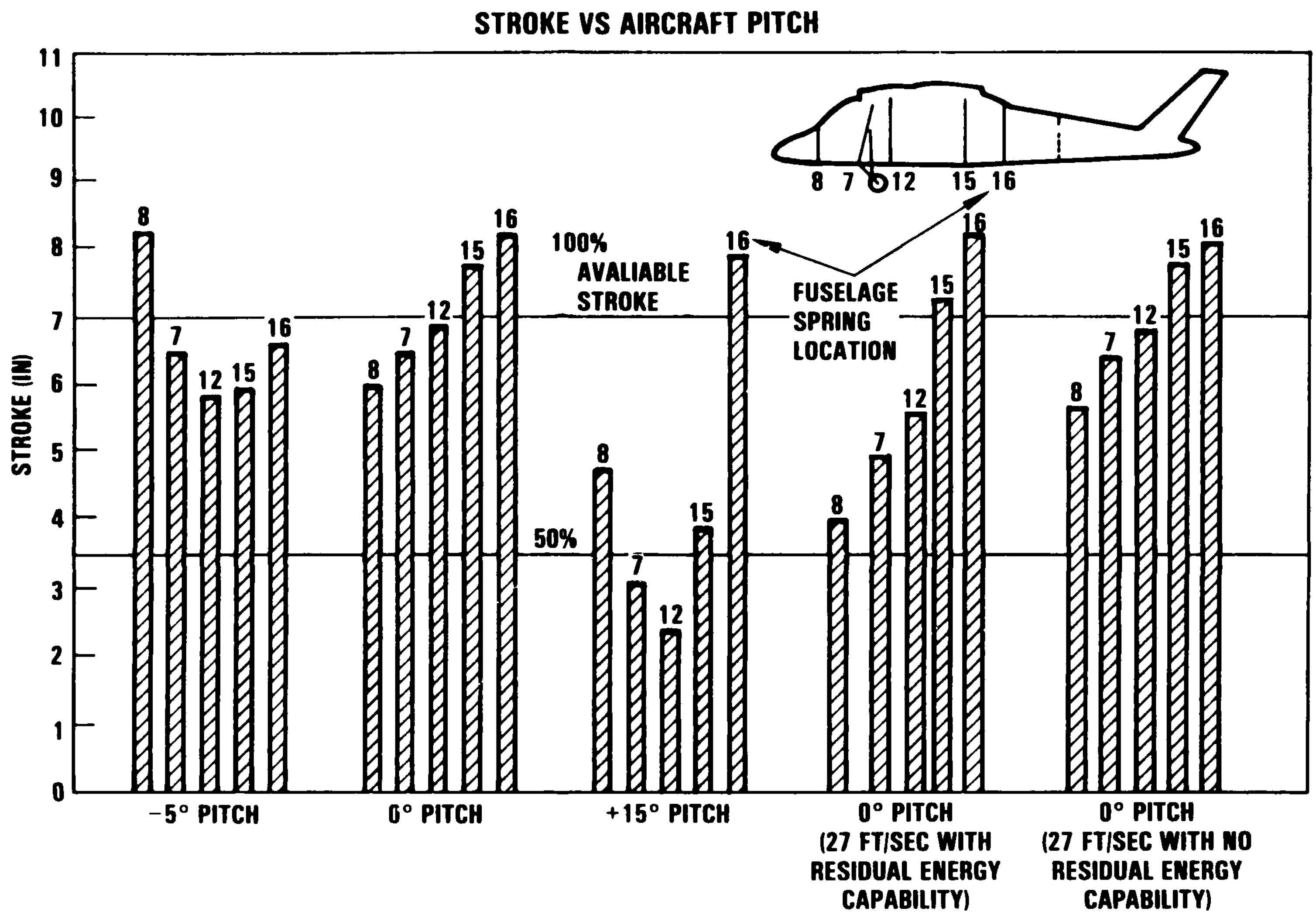


Figure 34. Fuselage subfloor crushing for symmetrical impact at 42 fps sink speed in Phase I study of coupled landing gear.

NOTES: (1) The impacts at 42 fps are with the gear extended.
(2) The impacts at 27 fps are with the gear retracted.

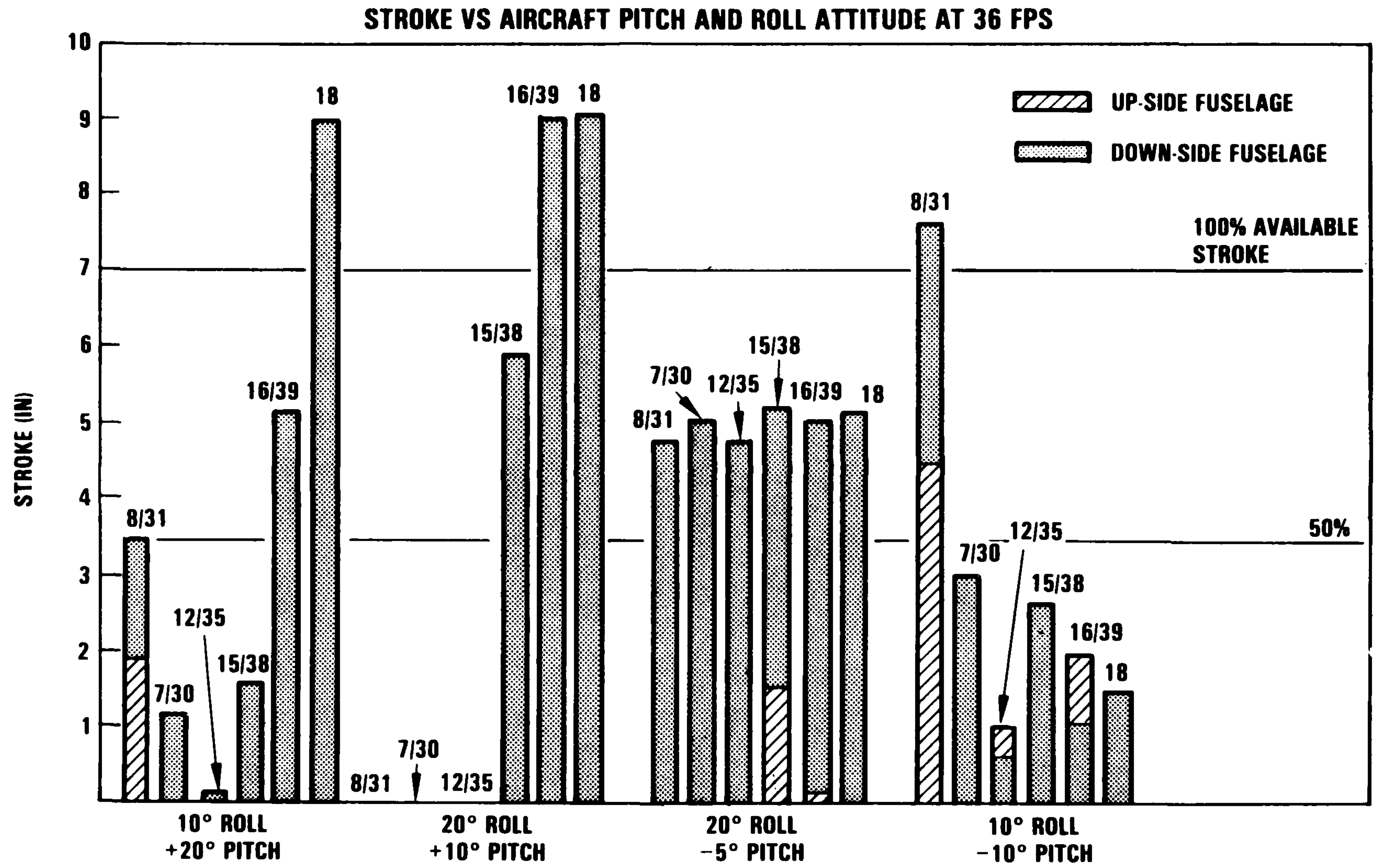


Figure 35. Fuselage crushing for nonsymmetrical impact at 36 fps sink speed in Phase I study of coupled landing gear.

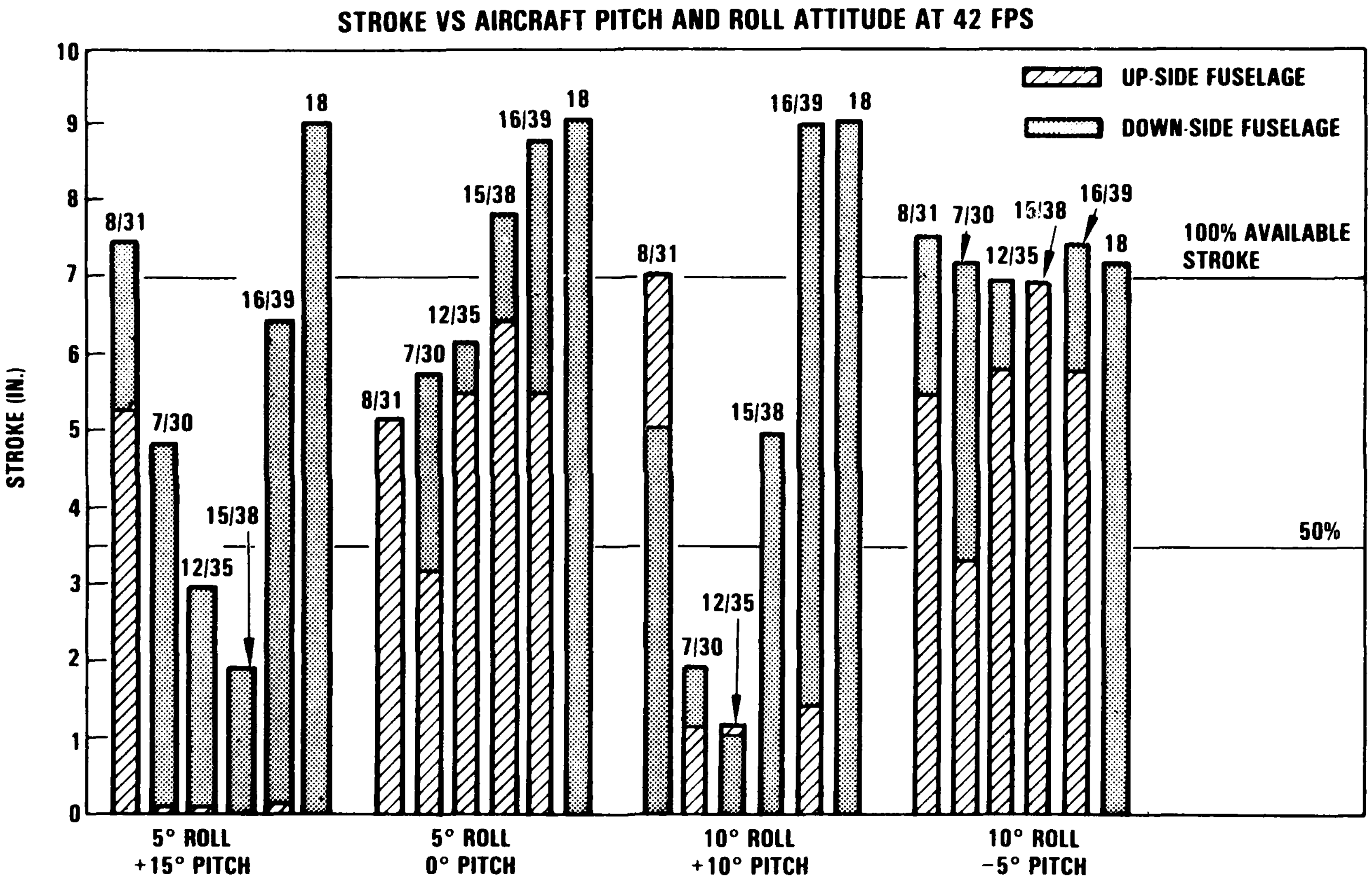


Figure 36. Fuselage crushing for nonsymmetrical impact at 42 fps sink speed in Phase I study of coupled landing gear.

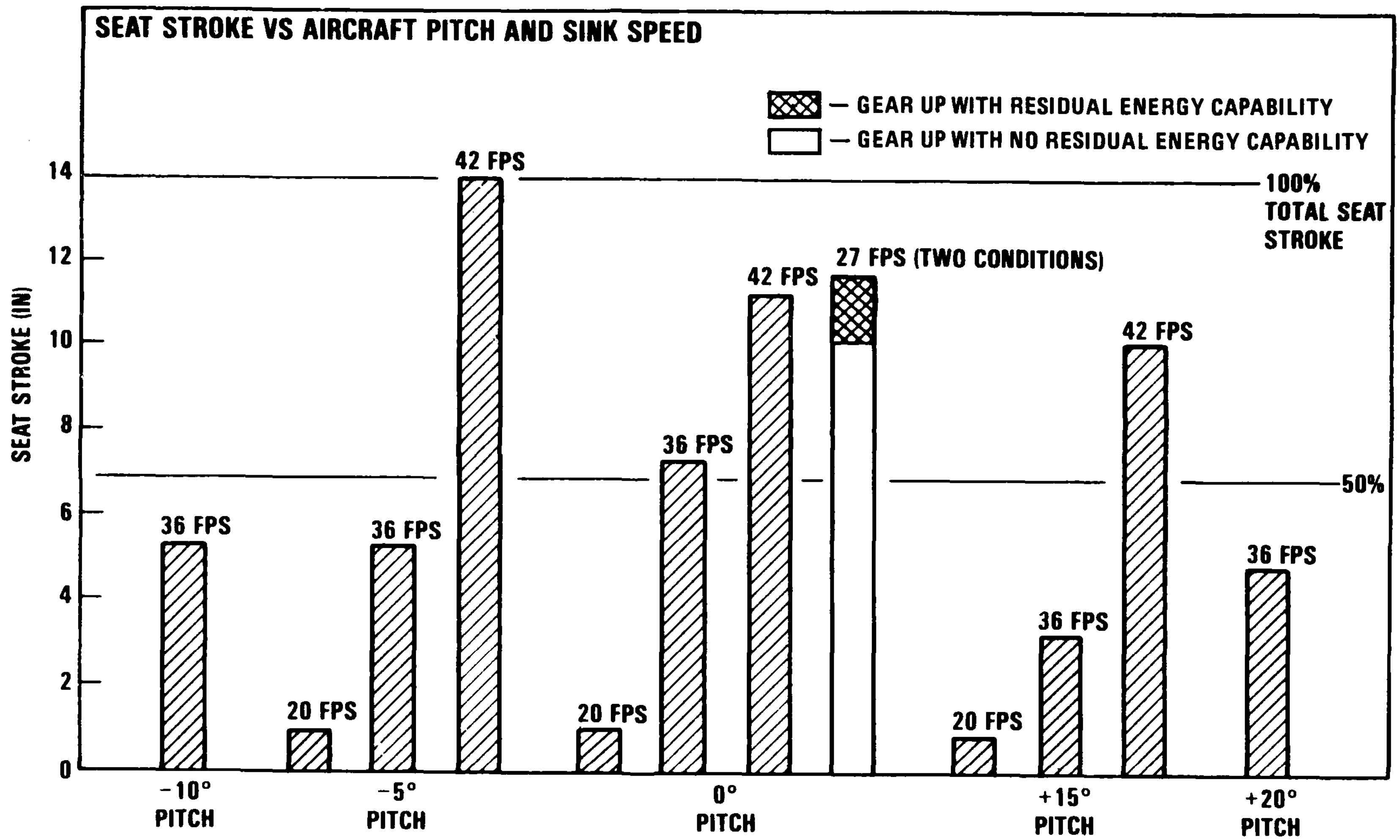


Figure 37. Occupant seat strokes for symmetrical impacts in Phase I study of coupled landing gear.

VERTICAL SINK SPEED AND PITCH ATTITUDE	DRI	PROBALILITY OF INJURY (%)	
		CADAVER	OPERATIONAL
20 FT SEC			
−5° (A)	16.1	2.5	0.7
0° (B)	16.6	4.0	1.2
+15° (C)	15.8	2.0	0.6
27 FT/SEC			
①0° (J)	19.8	27.0	13.0
②0° (K)	19.8	27.0	13.0
36 FT/SEC			
−10° (D)	17.2	6.0	1.8
−5° (E)	17.2	6.0	1.8
0° (F)	16.2	3.0	0.8
+15° (G)	18.7	16.0	7.0
+20° (H)	19.8	27.0	13.0
42 FT/SEC			
−5° (I)	19.3	21.0	9.0
0° (J)	17.0	5.0	1.8
+15° (K)	19.2	19.0	8.0

NOTES:
①GEAR UP, CAPABLE OF ABSORBING ENERGY
②GEAR UP WITH NO CAPABILITY OF ABSORBING ENERGY

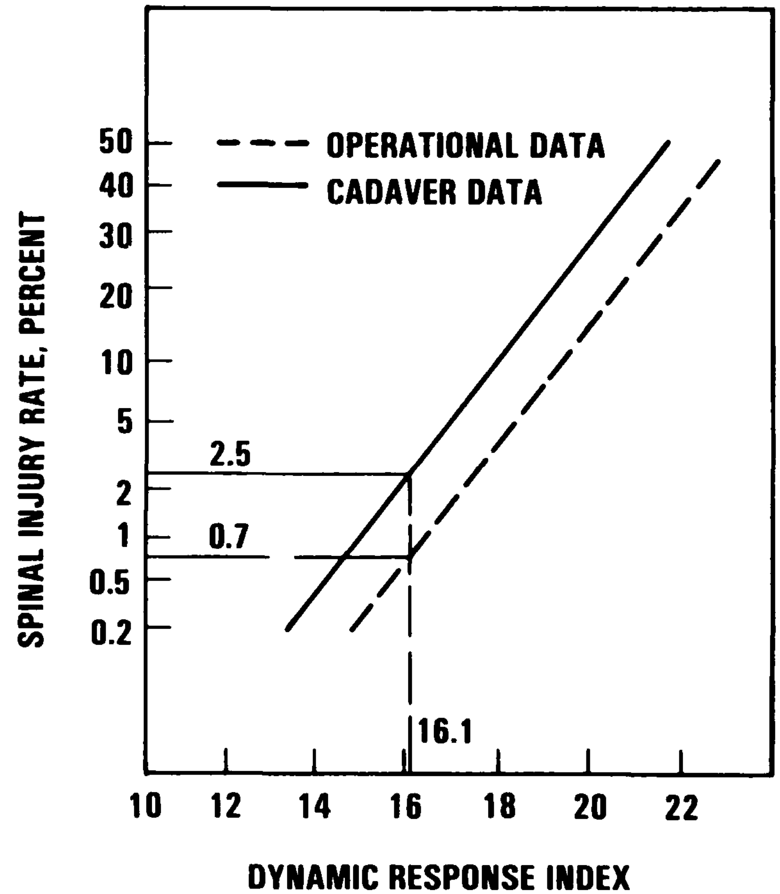


Figure 38. Occupant dynamic response index (DRI) for symmetrical impacts in Phase I study of coupled landing gear.

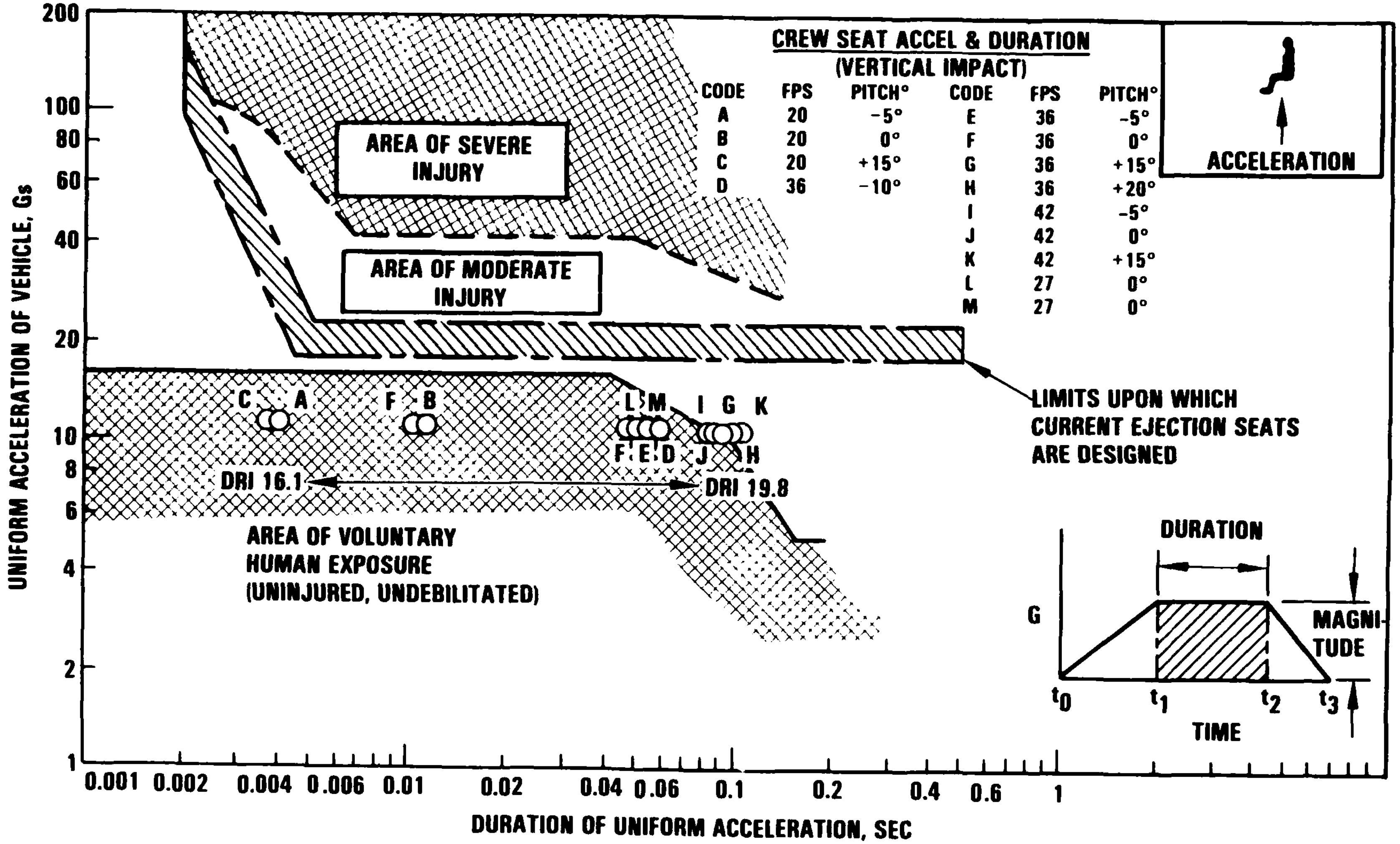


Figure 39. Acceleration levels experienced for symmetrical impacts in Phase I study of coupled landing gear shown on Eiband human tolerance curve.

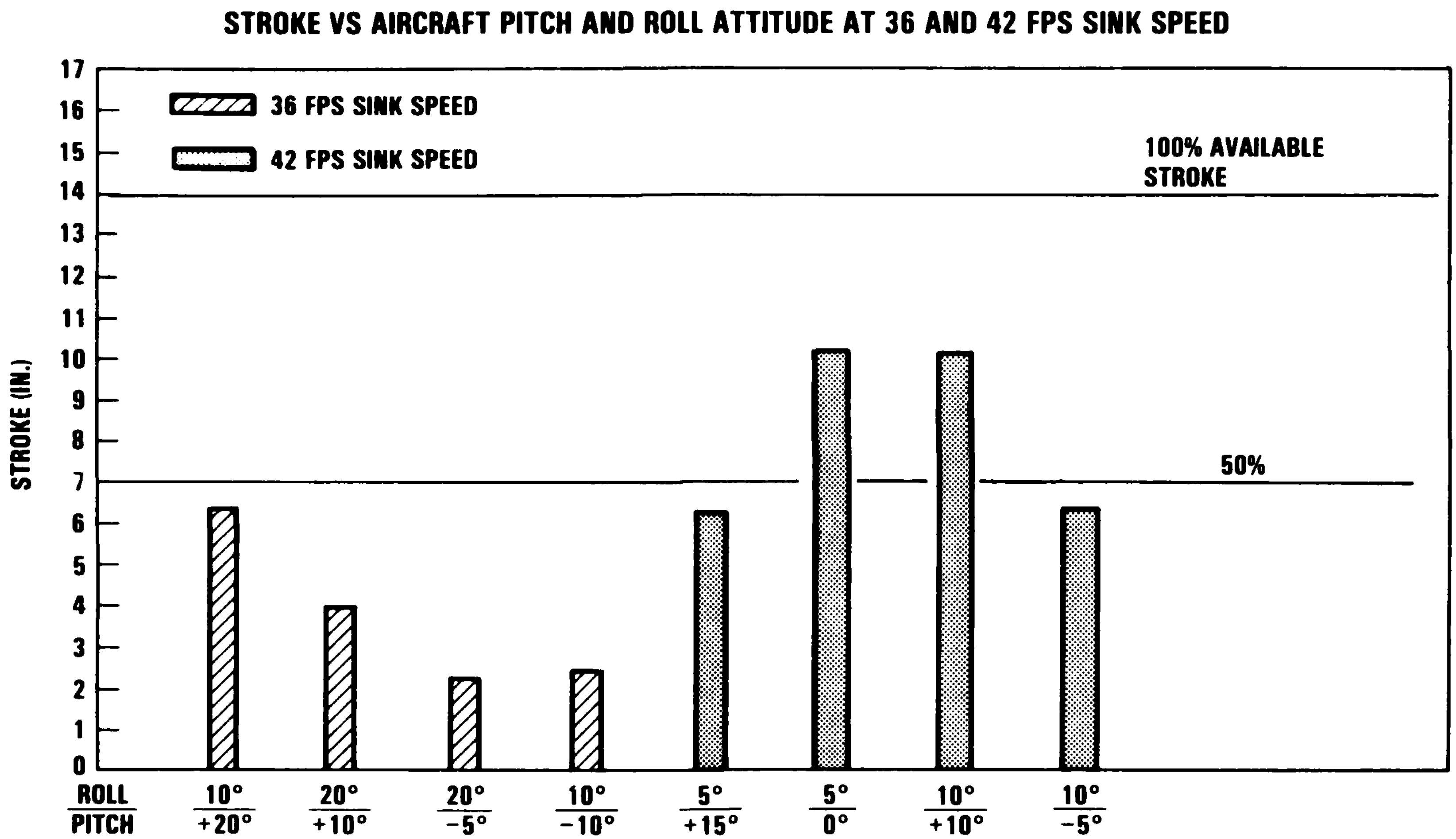


Figure 40. Occupant seat strokes for nonsymmetrical impacts in Phase I study of coupled landing gear.

VERTICAL SINK SPEED VS. ROLL & PITCH ANGLE	DRI	PROBABILITY OF INJURY (%)	
		CADAVER	OPERATIONAL
36 FPS ROLL, PITCH			
10° +20° (A)	19.3	21.0	9.0
20° +10° (B)	19.2	19.0	8.0
20° −5° (C)	17.5	7.0	2.5
10° −10° (D)	19.0	20.0	8.5
42 FPS ROLL, PITCH			
5° +15° (E)	19.9	28.0	14.0
5° 0° (F)	19.5	24.0	12.0
10° +10° (G)	19.4	23.0	11.0
10° −5° (H)	19.4	23.0	11.0

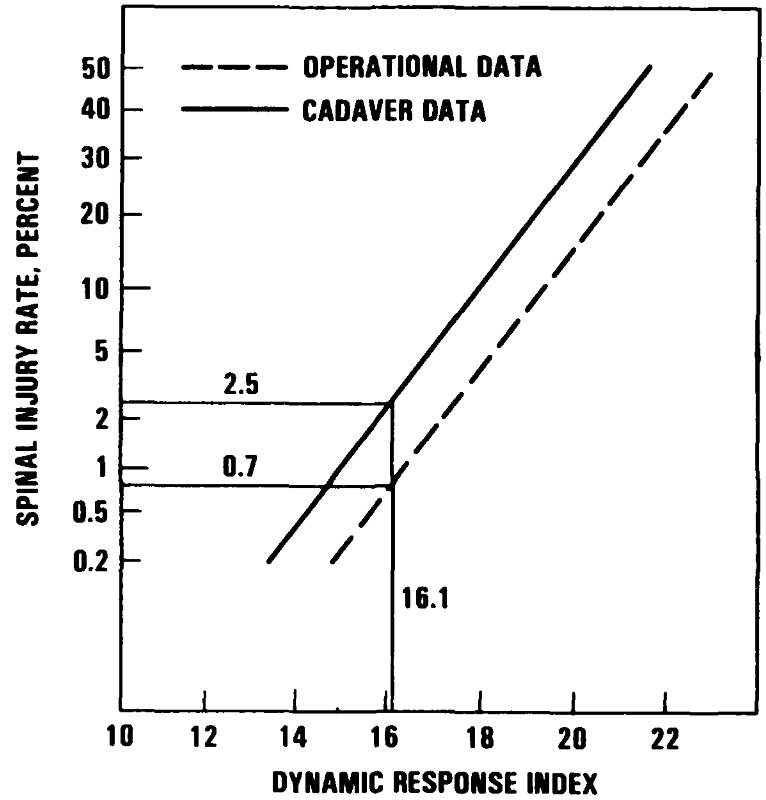


Figure 41. Occupant DRI for nonsymmetrical impacts in Phase I study of coupled landing gear.

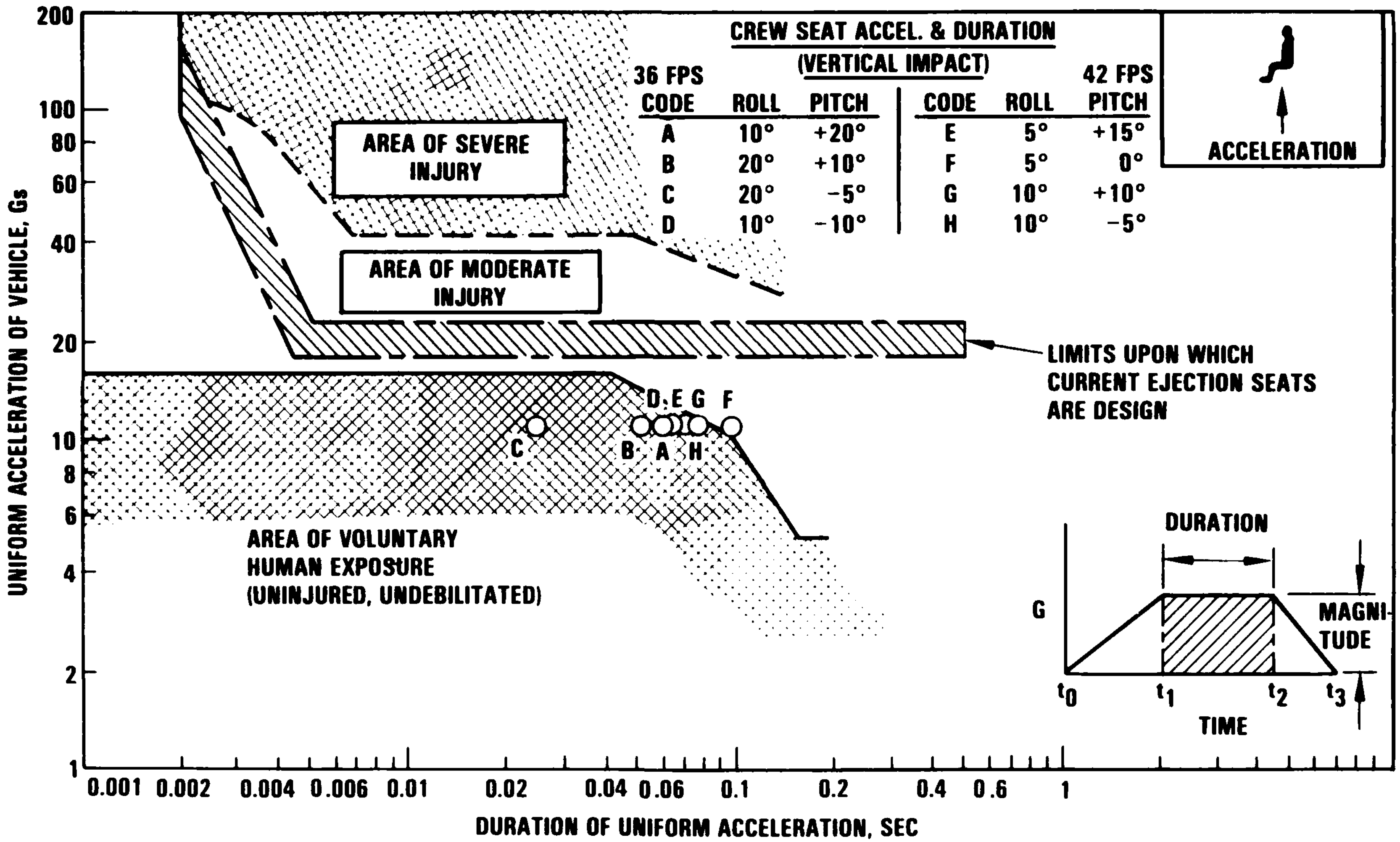


Figure 42. Acceleration levels experienced for nonsymmetrical impacts in Phase I study of coupled landing gear shown on Eiband human tolerance curve.

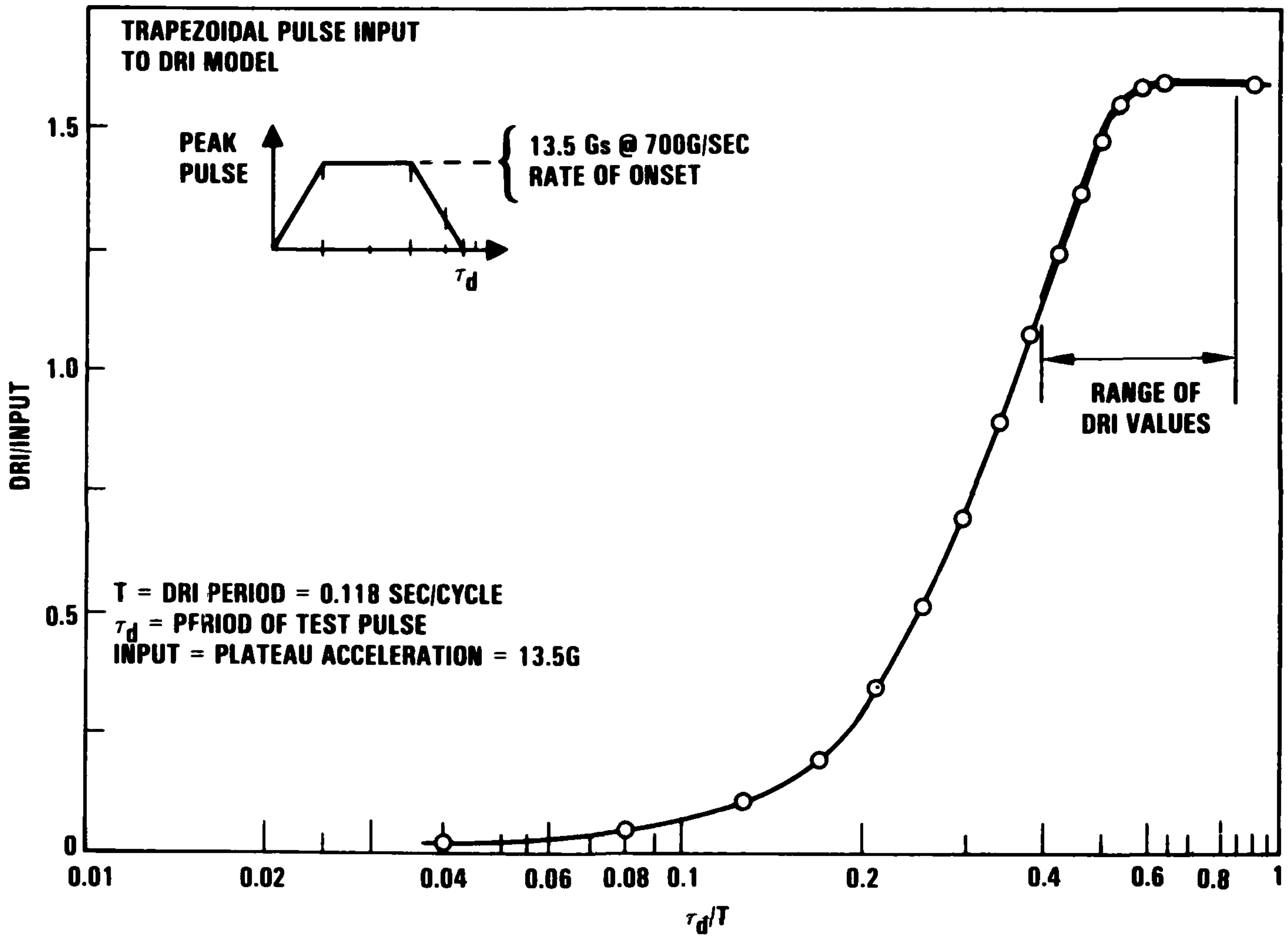


Figure 43. DRI as a function of pulse shape and duration with range of DRI values in Phase I study of coupled landing gear.

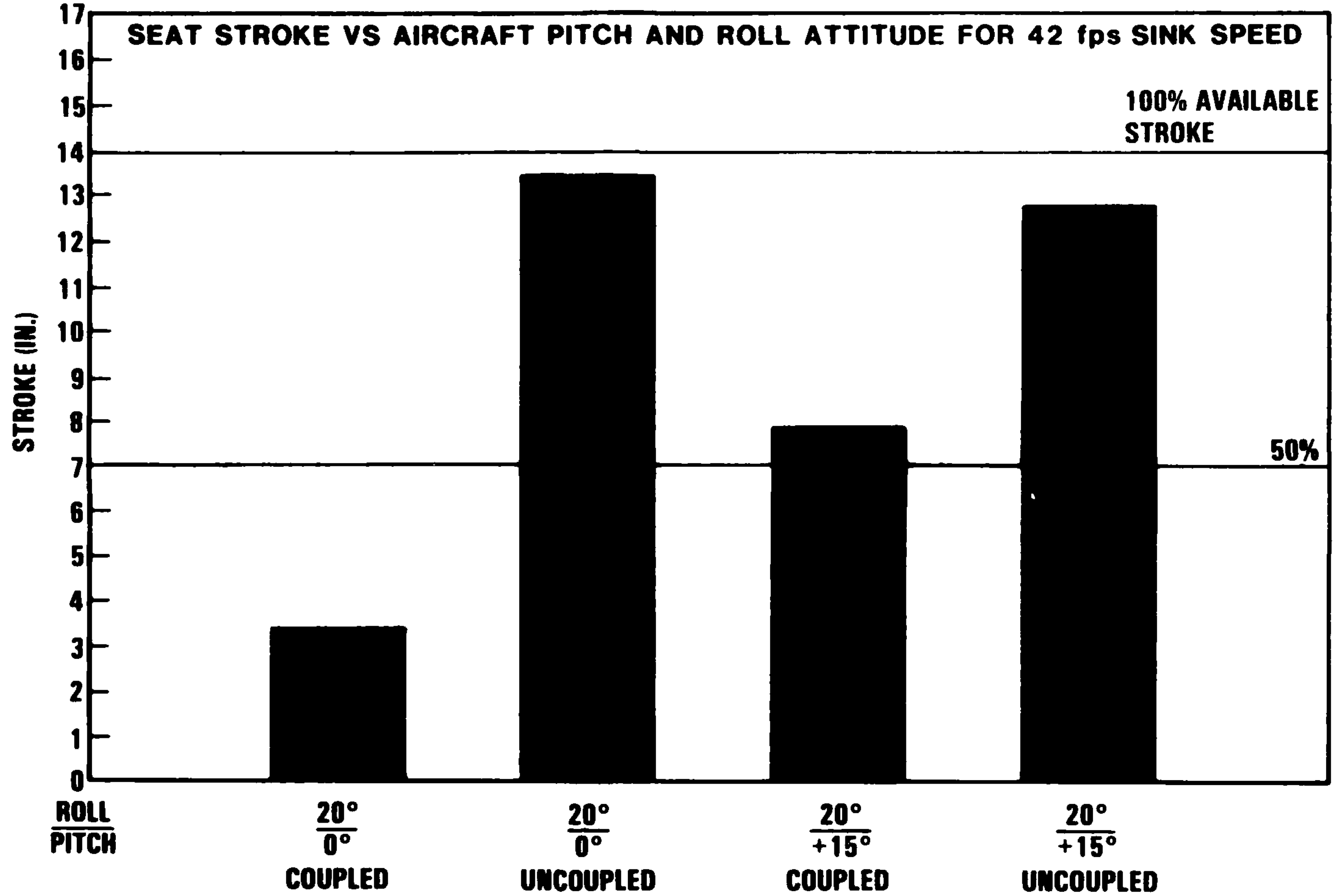


Figure 44. Occupant seat stroke with and without torque tube coupling for nonsymmetrical impacts in Phase I study.

One analysis with program KRASH was conducted to evaluate the influence of longitudinal velocity on occupant response. The analysis was conducted with a combined vertical sink speed of 42 fps and longitudinal speed of 25 fps at -5 degree pitch. The KRASH analysis indicated that the addition of a forward velocity component, for a crash-impact on an infinitely rigid surface, has no effect on occupant response in the vertical direction. This result is reasonable because normally the only energy absorbed by the fuselage due to a forward velocity component is frictional energy generated by the normal force in the fuselage crush zone and the contacting surface. Under most conditions, a longitudinal velocity crash condition is used only to analyze a soft field or obstructed runway landing where forward fuselage crash behavior is an important criterion in assessing occupant damage. Based on the results of this analysis, crash impact behavior involving a forward velocity component was not investigated further.

In summary, the results of KRASH analyses in Phase I provided confidence in the landing gear design and the systems approach to crashworthiness. Several patterns of crushing behavior which had not been expected were observed and used to refine the KRASH model for the Phase II study. The nature of these changes is discussed in Section 4.4.

4.4 REFINEMENT OF KRASH MODEL

The helicopter was sized in Phase I with the aid of simple and detailed KRASH models. The refinements incorporated in Phase II KRASH models were based on the Phase I results. The primary changes were in the modeling of the lower fuselage crush zone, but minor changes were also made to the landing gears and to the load limiter of the seat.

The fuselage crushing results, shown in Figures 33 and 34, indicate a nose-up pitching phenomenon during a 0-degree-roll and 0-degree-pitch impact. This resulted in disproportionate crushing of the aft fuselage in comparison to the forward fuselage. Normally, a nearly constant crushing along the fuselage length is expected for this impact condition. Two factors were the cause of this behavior: the concentration, or lumping, of crushable fuselage material about the fuselage cg caused an unbalanced moment about the cg; and the landing gear load factors were not consistent with the mass distribution in the fuselage.

The dense concentration of crushable structure forward of the aircraft cg resulted in a nose-up pitching tendency. The crushable underfloor structure was redistributed to reduce the pitching problem. The reconfiguration also proved beneficial in reducing the high accelerations which occur during extreme pitch and roll impact conditions. Extreme nose-up or nose-down pitch, or extreme roll, impacts result in large localized crushing of the structures that impact first. Typically, the crushing deformation exceeds the available crushing distance, resulting in higher uncontrolled acceleration levels. It was felt that by increasing the energy absorbing capability along the fuselage perimeter, as viewed from the plan view of the helicopter, the magnitudes of the accelerations would be more controllable. The "strengthening" of the perimeter

was achieved by designing the lower fuselage with two keel beams and separating them as far as practicable. The overall fuselage load level was maintained at 15g but was increased to approximately 20g locally along the fuselage perimeter.

The preliminary weights analysis had indicated that the weight distribution between the main and tail landing gears was 75 percent and 25 percent, respectively. The distribution calculated by program KRASH was 73 percent and 27 percent. Since the main landing gear had been sized to react a higher inertia load and the tail gear a lower inertia load, the unbalanced reaction about the aircraft cg resulted in the nose-up pitching tendency. The problem was remedied by sizing the landing gears to agree with the results of the KRASH analysis.

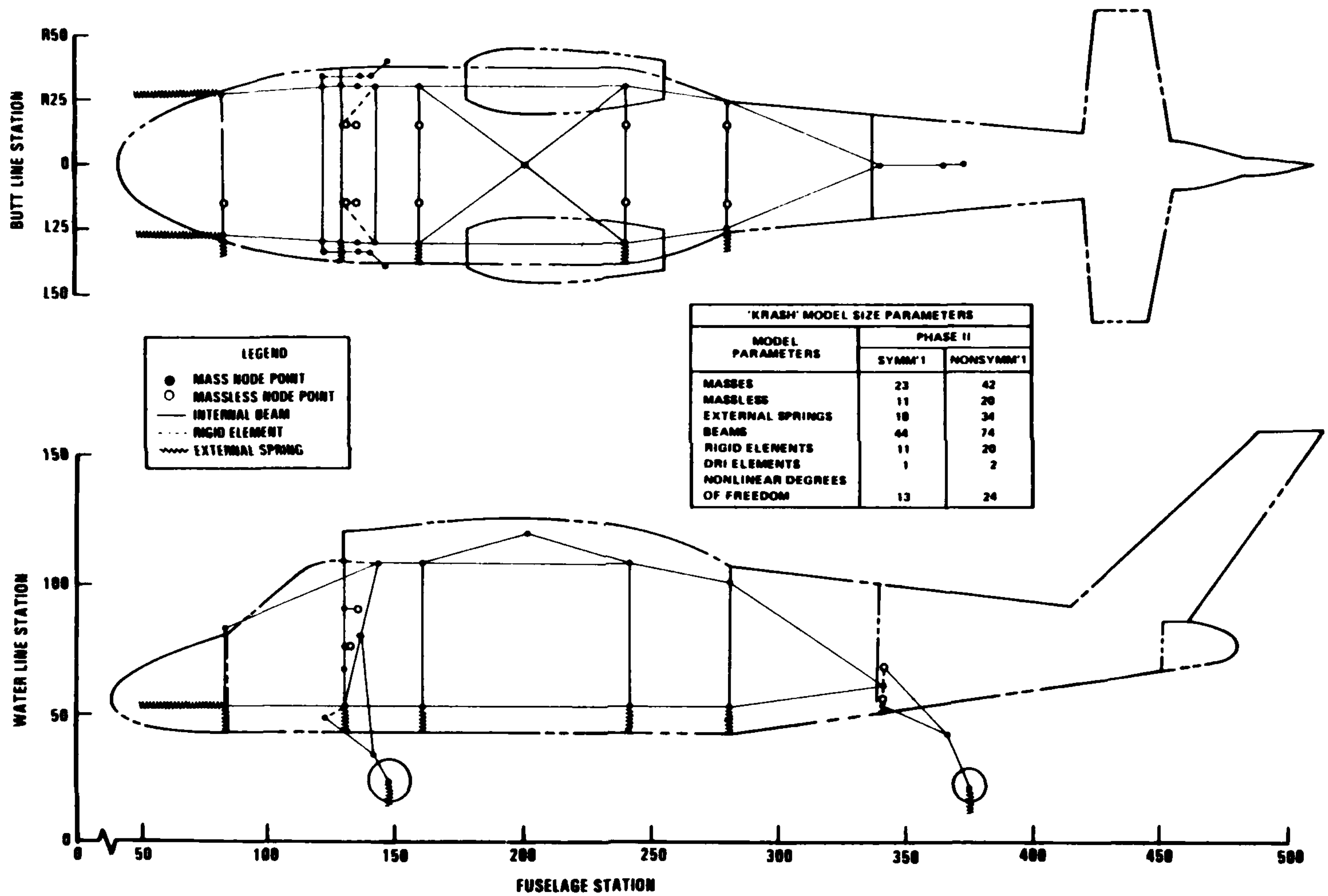
During the Phase I study, the crew seat stroking load was based on that of the AH-64 helicopter, which exhibited a 13.5g load level during tests. To bring the Phase II seat model more in line with the thrusts of present industry and Government standards, the seat load limiter was increased to 14.5g for a 50th percentile occupant. This change generally resulted in higher DRIs but shorter seat strokes.

The resulting KRASH model for Phase II is shown in Figure 45, and an isometric view of the nonsymmetrical model in Figure 46. A comparison of the size parameters of Phases I and II KRASH models is given in Table 13 and the system design acceleration is shown in Figure 47. The Phase II KRASH model for the occupant is the same as that shown in Figure 22.

4.5 PHASE II KRASH ANALYSIS

The Phase II analysis of crash impact behavior was conducted with the refined KRASH model described above. The design envelope of roll and pitch angles is given in Figure 48. The analyses for crash impact of the retractable landing gear in the extended position and of the fixed landing gear were conducted for sink speeds of 42, 36, 30, 20, and 15 fps. Additional analyses for impact with the gear retracted were conducted for sink speeds of 35, 30 and 25 fps. For each sink speed, all sixteen combinations of roll and pitch angles were analyzed.

The range of strokes of the main landing gear oleo for a 42 fps impact are shown in Figure 49 and the tail landing gear oleo in Figure 50. As the roll angle increases, the stroke of the down-side main gear increases, with maximum stroke occurring for a 15-degree roll and 0-degree pitch impact. In contrast, the tail gear strokes are almost identical for 0, 5-and 10-degree roll impacts but increase from -5-degree pitch to +15-degree pitch within each roll envelope. Overall, the tail gear stroke decreased slightly for the 15-degree roll impact condition. The magnitudes of the strokes of both landing gears for all impact conditions are given in Table 14. The landing gear strokes at the extremes of the design envelope for all sink speeds are graphically illustrated in Figure 51. The importance of the torque tube is illustrated by the large percentage of energy absorbed by the up-side gear and is shown in Figure 52. The fuselage without the benefit of the torque tube must be designed to absorb



'KRASH' MODEL SIZE PARAMETERS		
MODEL PARAMETERS	PHASE II	
	SYMM'1	NONSYMM'1
MASSES	23	42
MASSLESS	11	20
EXTERNAL SPRINGS	10	34
BEAMS	44	74
RIGID ELEMENTS	11	20
DRI ELEMENTS	1	2
NONLINEAR DEGREES OF FREEDOM	13	24

Figure 45. Symmetrical and nonsymmetrical 'KRASH' models for Phase II study.

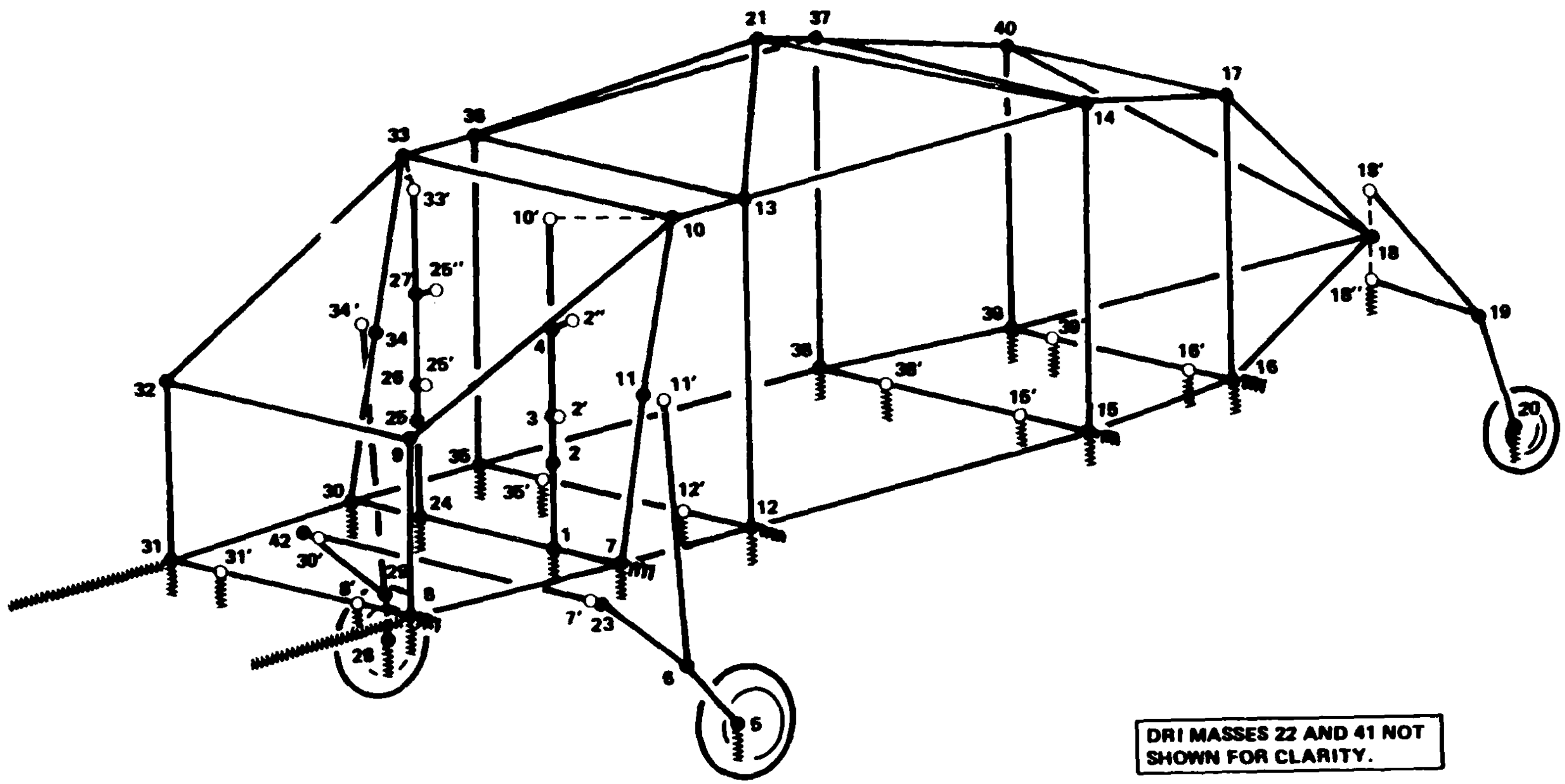


Figure 46. Isometric view of the nonsymmetrical 'KRASH' model for Phase II study.

TABLE 13. COMPARISON OF KRASH MODEL SIZE PARAMETERS OF PHASE I AND PHASE II

MODEL PARAMETERS	PHASE I		PHASE II	
	SYMM'L	NON-SYMM'L	SYMM'L	NON-SYMM'L
BEAMS	41	72	44	74
DRI ELEMENTS	1	2	1	2
EXTERNAL SPRINGS	8	24	18	34
MASSES	22	42	23	42
MASSLESS NODES	6	10	11	20
NONLINEAR DEGREES OF FREEDOM	10	22	13	24
RIGID ELEMENTS	6	10	11	20

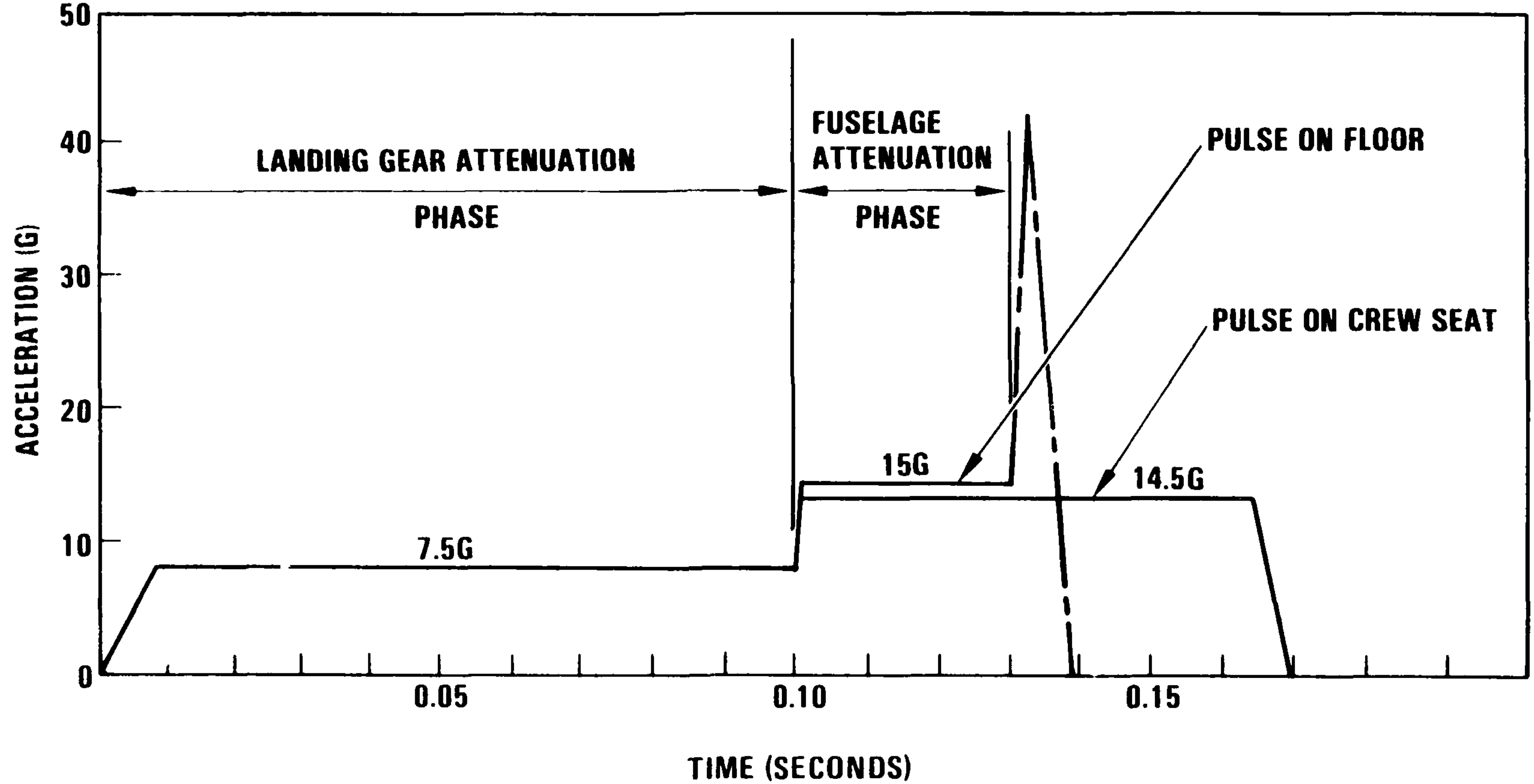


Figure 47. Design accelerations for severe vertical impacts for Phase II study.

AD-A158 816 ADVANCED TECHNOLOGY HELICOPTER LANDING GEAR PRELIMINARY DESIGN INVESTIGAT..(U) HUGHES HELICOPTERS INC CULVER CITY CA J K SEN ET AL. JUL 85 HHI-84-284 2/3

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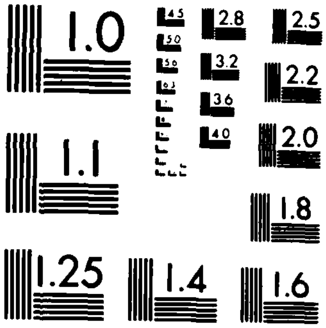


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963 A

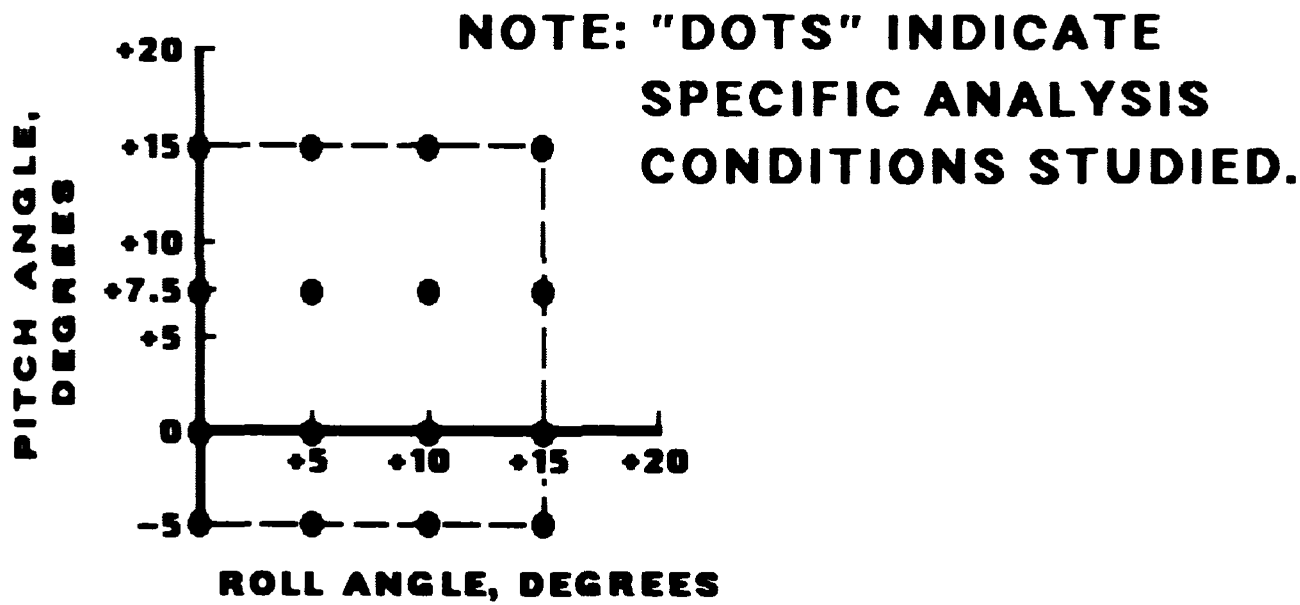


Figure 48. Crash envelope of roll and pitch angles for Phase II study.

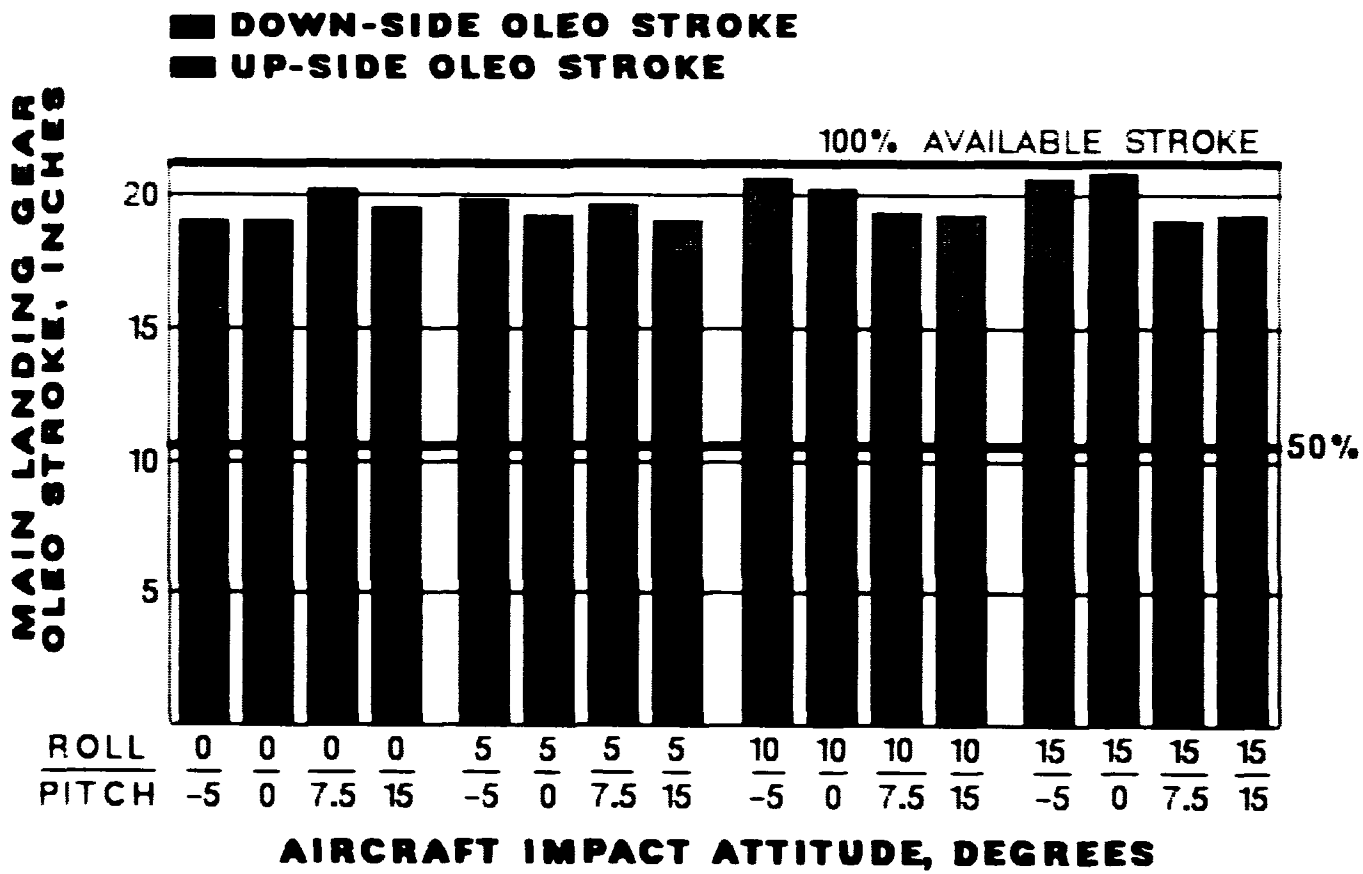


Figure 49. Coupled main landing gear oleo stroke for 42 fps impact in Phase II study.

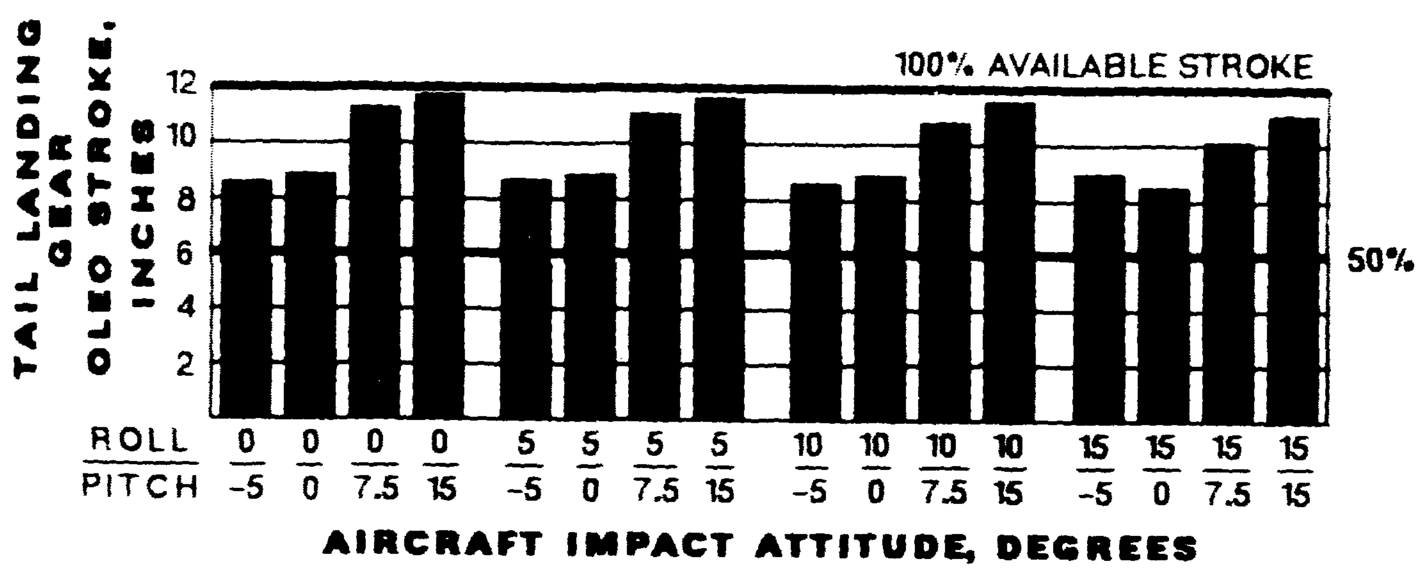


Figure 50. Tail landing gear oleo stroke for 42 fps impact in Phase II study.

TABLE 14. COUPLED MAIN AND TAIL LANDING GEAR STROKES VERSUS SINK SPEED AND AIRCRAFT ATTITUDE IN PHASE II STUDY (STROKES IN INCHES)

AIRCRAFT IMPACT ATTITUDE, DEG.		AIRCRAFT IMPACT VELOCITY AND OLEO STROKES														
		42 fps			36 fps			30 fps			20 fps			15 fps		
ROLL	PITCH	LMLG[a]	RMLG[b]	TLG[c]	LMLG	RMLG	TLG	LMLG	RMLG	TLG	LMLG	RMLG	TLG	LMLG	RMLG	TLG
0	-5	19.0	19.0	8.5	16.0	16.0	7.1	14.9	14.9	6.1	12.7	12.7	3.6	9.5	9.5	2.7
0	0	19.1	19.1	9.0	15.8	15.8	7.9	15.7	15.7	6.6	12.0	12.0	4.7	8.5	8.5	3.6
0	7.5	20.3	20.3	11.3	16.4	16.4	9.8	15.6	15.6	7.3	11.8	11.8	4.7	9.1	9.1	3.3
0	15	19.6	19.6	11.8	15.9	15.9	9.5	14.0	14.0	6.8	11.8	11.8	4.8	7.5	7.5	3.4
5	-5	19.8	17.7	8.7	16.9	15.5	7.1	15.7	14.2	6.3	13.3	12.5	3.7	9.4	9.3	2.7
5	0	19.3	18.0	8.9	16.6	15.2	7.8	16.0	14.4	6.5	12.5	11.4	4.7	8.8	8.3	3.6
5	7.5	19.5	18.7	11.2	16.7	15.2	9.6	16.2	13.8	7.3	12.2	10.8	4.8	9.1	8.4	3.3
5	15	19.0	17.8	11.7	16.3	14.7	9.5	14.2	13.0	6.8	11.5	10.2	4.8	10.1	9.1	3.4
10	-5	20.5	16.9	8.7	17.1	15.5	7.1	14.9	14.2	6.3	12.3	12.5	3.6	7.6	8.6	2.6
10	0	20.2	16.7	8.8	17.2	15.4	7.6	14.9	14.3	6.5	11.6	10.7	4.7	8.2	7.1	3.6
10	7.5	19.3	15.7	10.8	16.2	14.3	9.4	15.0	13.6	7.3	11.0	10.4	5.0	8.4	6.9	3.5
10	15	19.2	14.9	11.6	17.9	14.6	7.1	14.2	11.9	6.7	11.7	7.5	4.8	9.6	7.6	3.4
15	-5	20.6	17.2	8.9	17.9	14.6	7.1	15.1	13.8	6.1	12.1	10.9	3.8	9.1	6.9	2.6
15	0	20.7	16.7	8.5	17.9	14.1	7.5	14.9	13.2	6.2	11.6	9.2	4.7	8.8	5.4	3.4
15	7.5	19.0	15.6	10.2	17.4	14.2	9.1	14.5	11.7	7.3	11.5	8.4	5.1	9.0	6.2	3.4
15	15	19.3	15.1	11.1	17.7	13.3	9.3	15.5	10.4	6.6	12.6	9.5	4.7	10.3	7.5	3.3

[a]LMLG IS THE ACRONYM FOR LEFT MAIN LANDING GEAR
[b]RMLG IS THE ACRONYM FOR RIGHT MAIN LANDING GEAR
[c]TLG IS THE ACRONYM FOR TAIL LANDING GEAR

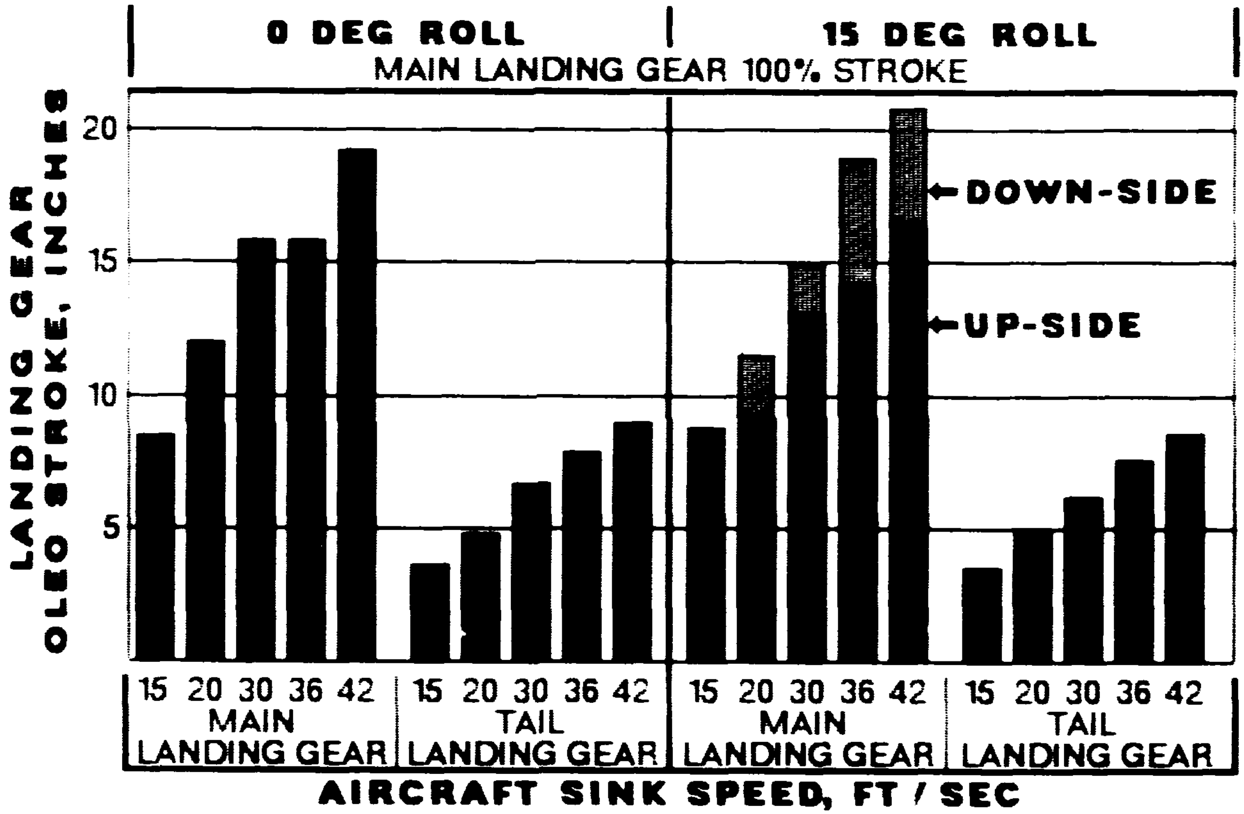


Figure 51. Coupled landing gear strokes at the extremes of the design envelope for 0 degree pitch in Phase II study.

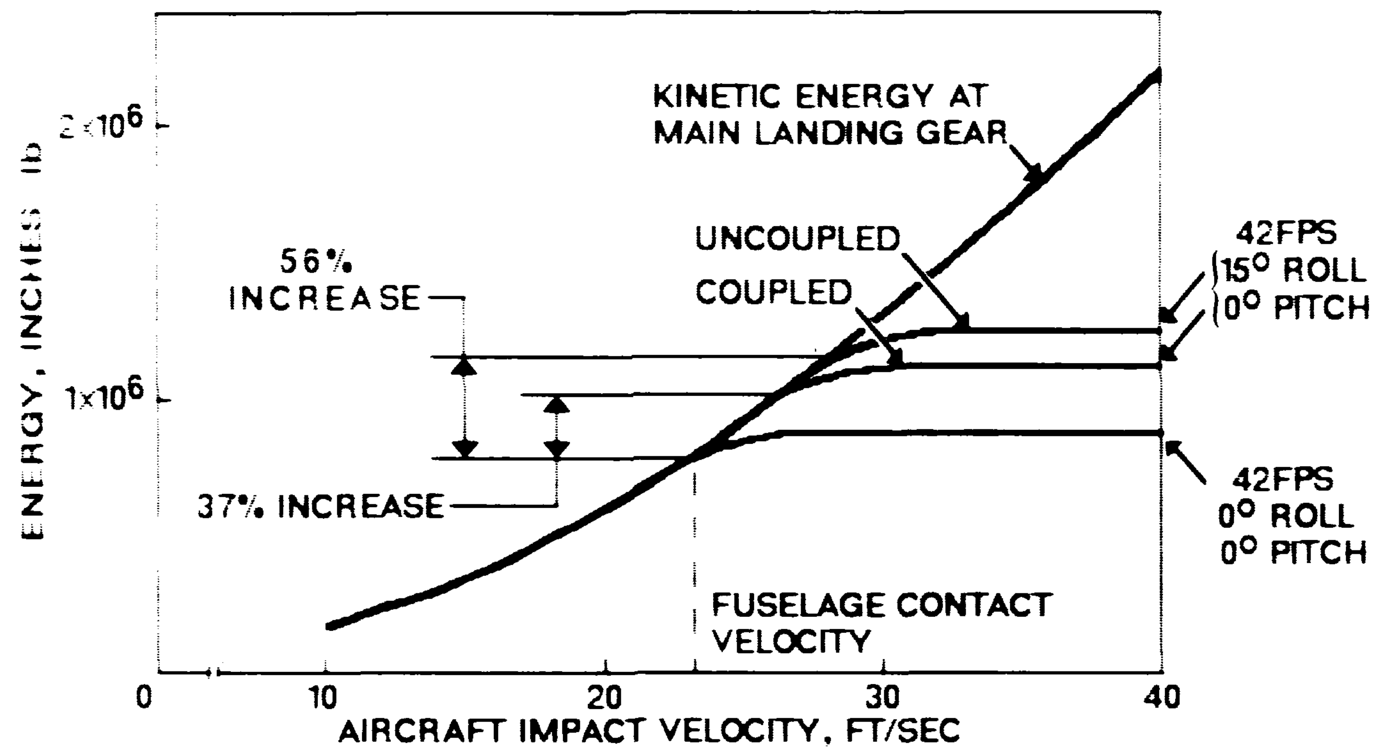


Figure 52. Energy absorbed by the coupled and uncoupled main landing gears in Phase II study.

50 percent more energy than the fuselage with the torque tube in comparing the energy absorbed by the landing gear for a 0- and 15-degree roll impact at 42 fps.

The fuselage is divided into three regions to simplify the analysis of the underfloor deformations: the nose region, Sta 40.0 to Sta 133.0; mid region, Sta 133.0 to Sta 280.6; and tail region, Sta 280.6 to Sta 339.0. For all roll impact attitudes with the landing gear extended, the nose region exhibits the largest deformation except for 15 degrees roll impact for sink speeds greater than 36 fps. The maximum deformations for each fuselage region versus sink speed and roll angle are shown in Figures 53 through 56. The total deformation envelope for all roll conditions is presented in Figure 57. Details of all fuselage deformations with the landing gear extended are given in Figures A-1 through A-12 and in Tables B-2 through B-4.

The fuselage deformations with the landing gear retracted indicate that the largest deformations occur in the nose region for crash impact at 0 degree pitch and 0, 5 and 10 degrees roll angle for all sink speeds. However, for 15 degrees roll the tail region suffers the largest deformation. These are graphically exhibited in the envelope plots shown in Figures 53 through 57. Details of all fuselage deformations with the landing gear retracted are given in Figures A-13 through A-24 and in Tables B-5 through B-7.

In comparing fuselage deformations for the two positions of the landing gear, maximum deformation for all sink speeds with the gear retracted is greater than the maximum predicted deformation at 42 fps with the gear extended. These results are illustrated in Figure 58.

The envelope of occupant seat strokes is shown in Figure 59. The maximum seat stroke for a crash with the landing gear extended is about 54 percent of the available seat stroke. In contrast, the available seat stroke distance is exceeded at velocities above 30 fps with the landing gear retracted. The figure also shows that, on the basis of the seat stroke, the 25 fps landing gear retracted impact was of about the same severity as the 42 fps landing gear extended impact. The plots of the seat strokes during impact for both positions of the landing gear are given in Figures C-1 through C-8. Data for the seat strokes and the DRIs are presented in Tables 15 and 16.

4.6 DISCUSSION OF PHASE II KRASH ANALYSIS RESULTS

In comparing Phase II KRASH analysis results with the Phase II impact conditions, all requirements were met except for the following:

- Occasional nose strikes occurred at impact sink speeds of 20 fps with the landing gear extended

- Some occupant injuries were indicated at impact sink speeds of 35 fps with the landing gear retracted

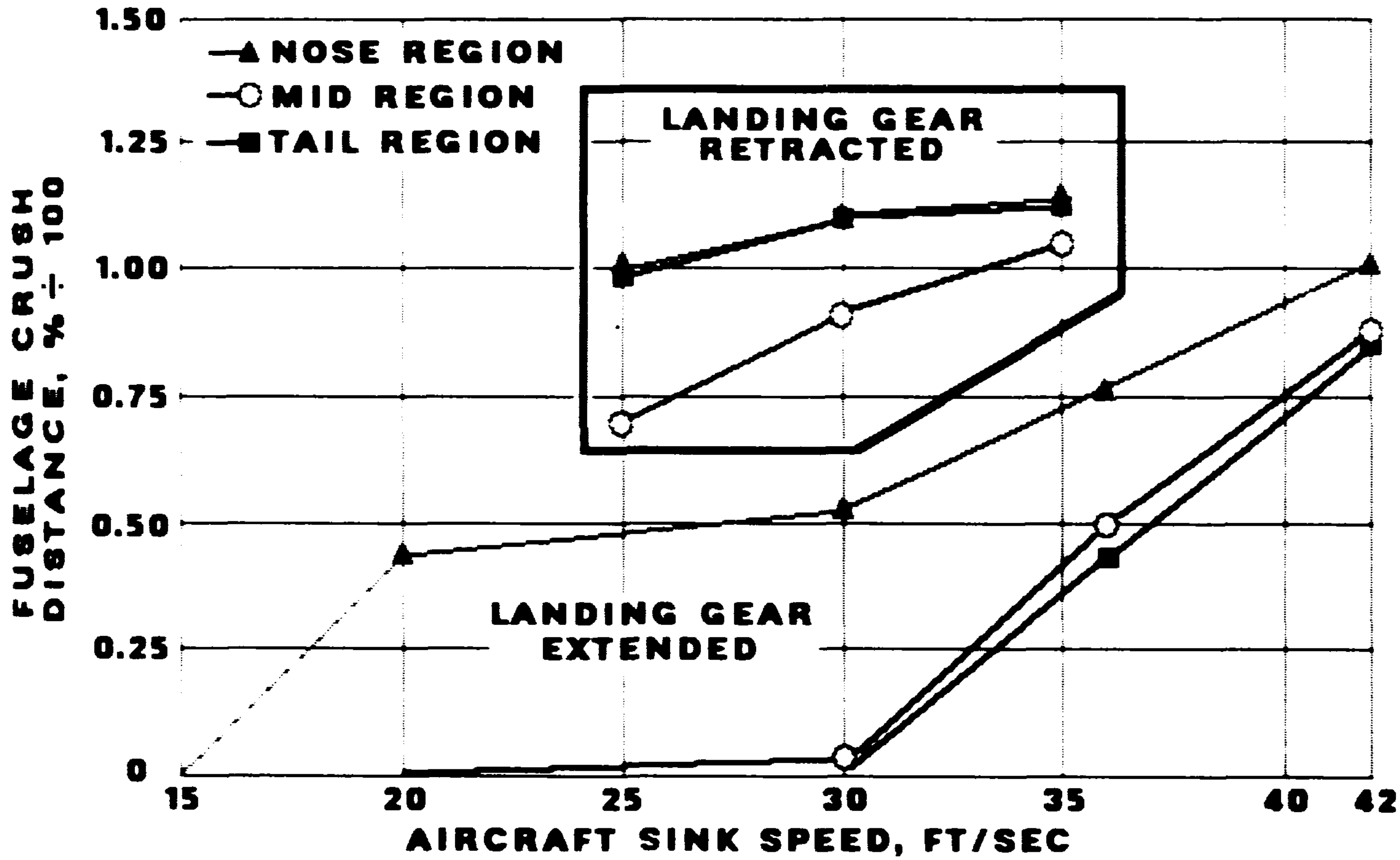


Figure 53. Envelope of fuselage deformations for 0-degree roll impact condition in Phase II study of coupled landing gear.

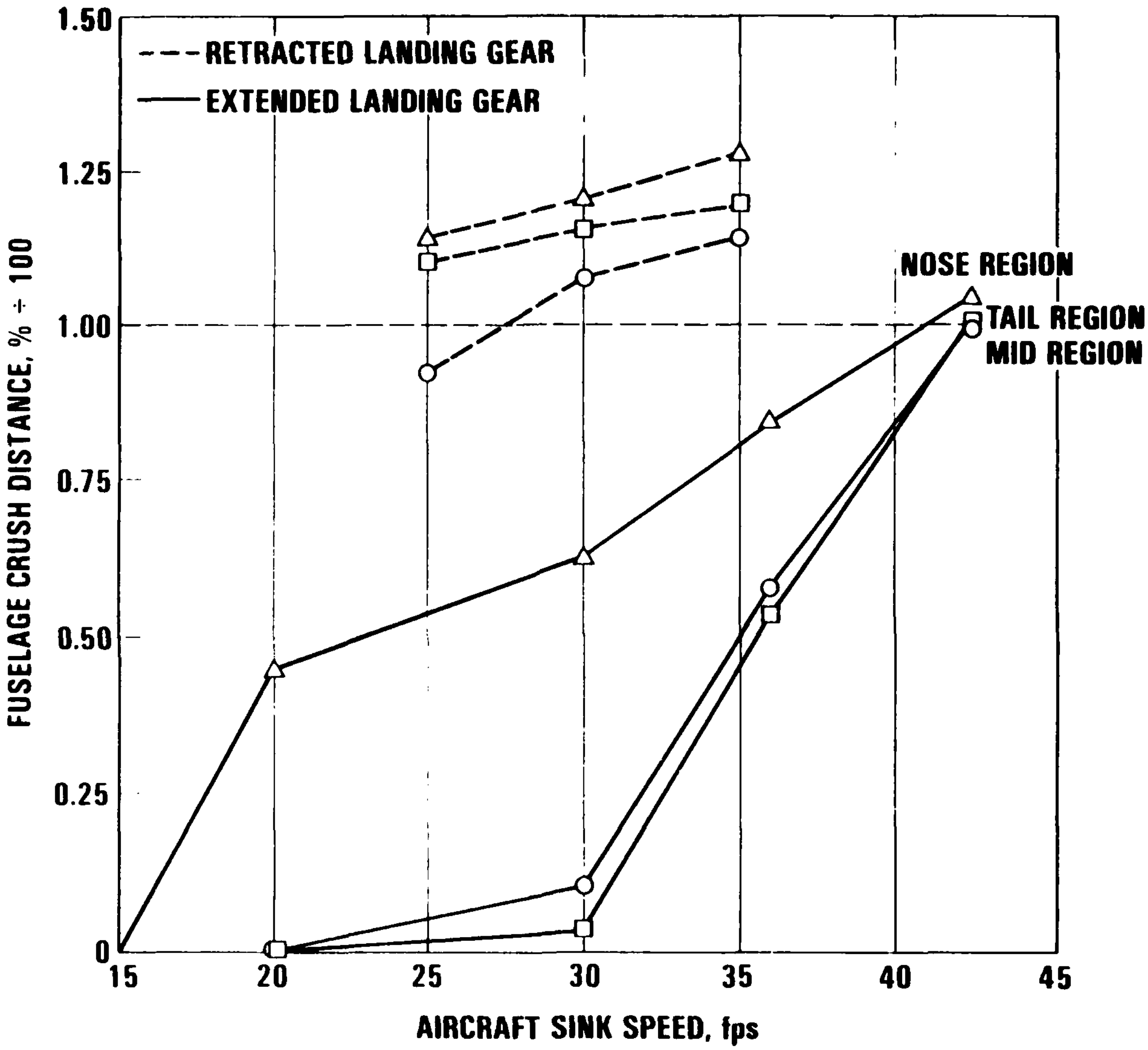


Figure 54. Envelope of fuselage deformations for 5-degree roll impact condition in Phase II study of coupled landing gear.

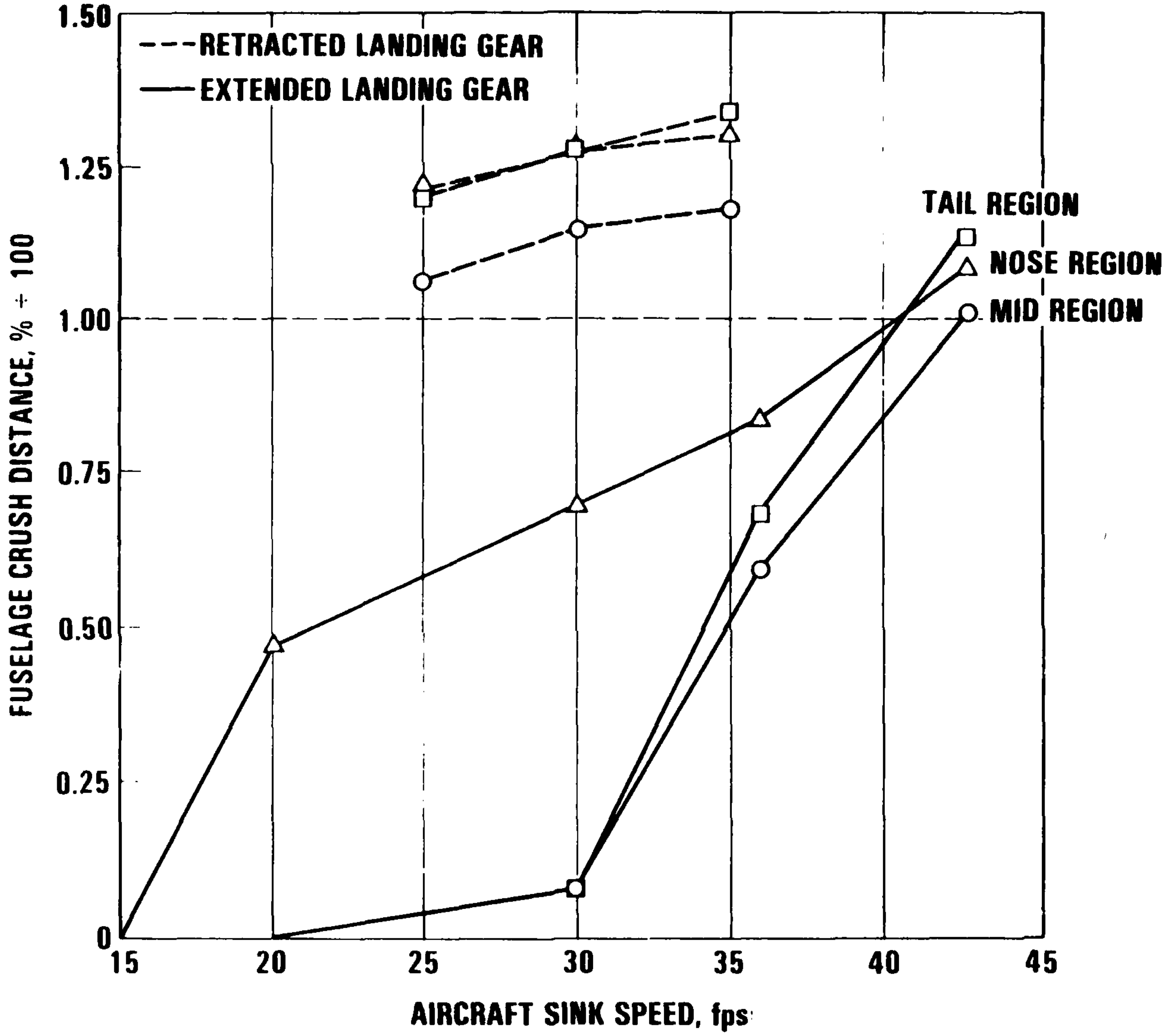


Figure 55. Envelope of fuselage deformations for 10-degree roll impact condition in Phase II study of coupled landing gear.

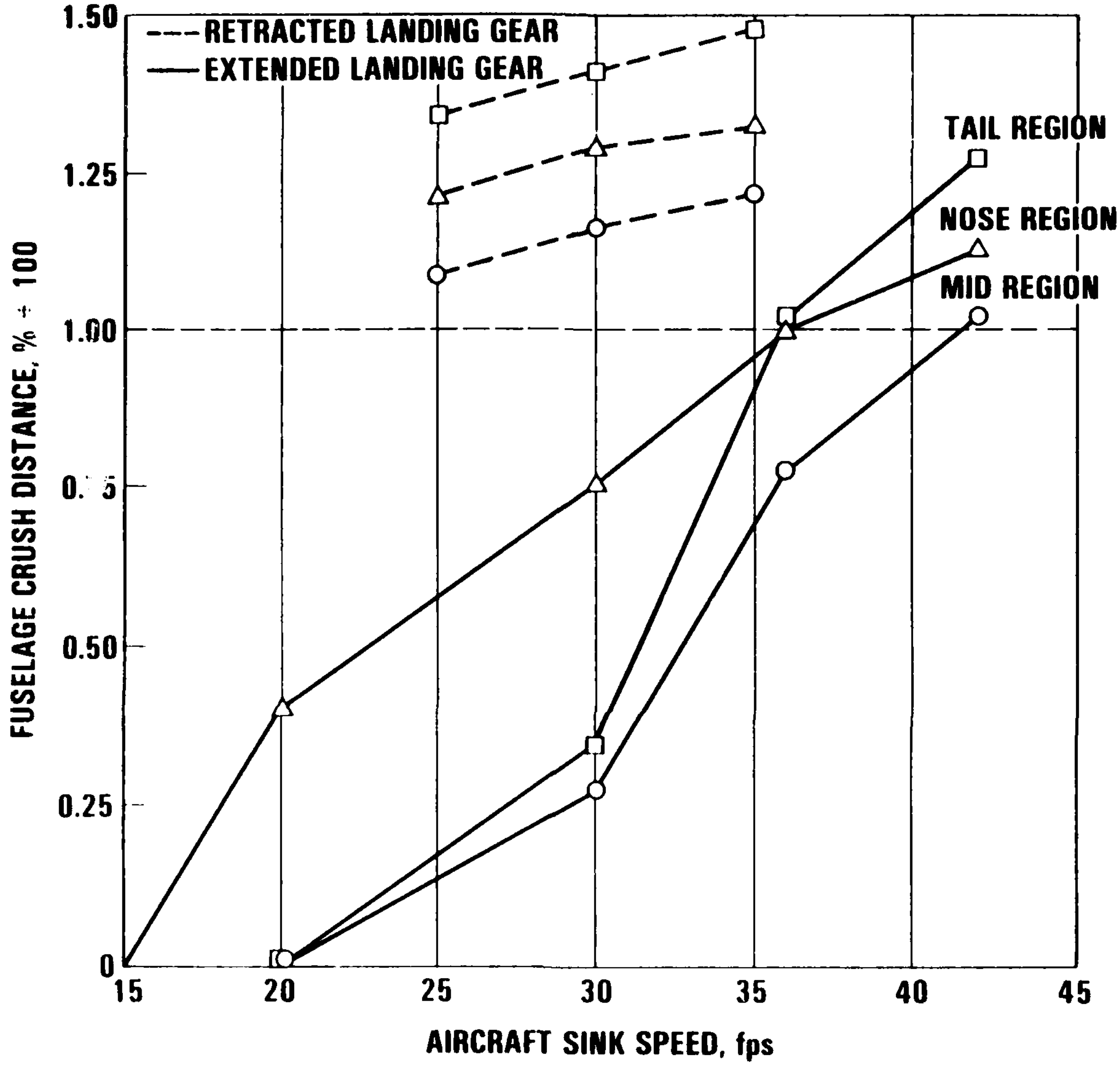


Figure 56. Envelope of fuselage deformations for 15-degree roll impact condition in Phase II study of coupled landing gear.

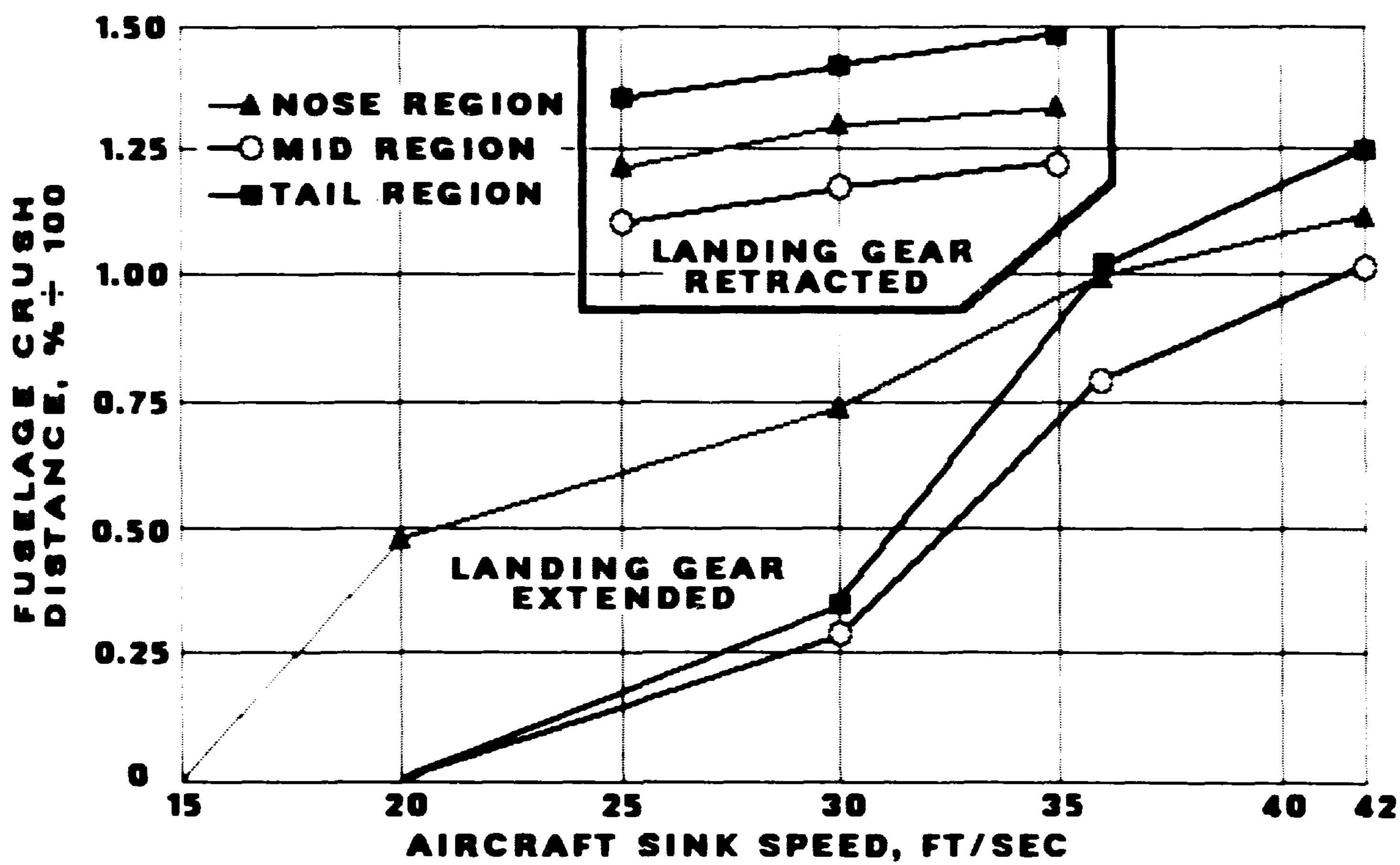


Figure 57. Total envelope of fuselage deformations for all roll impact conditions in Phase II study of coupled landing gear.

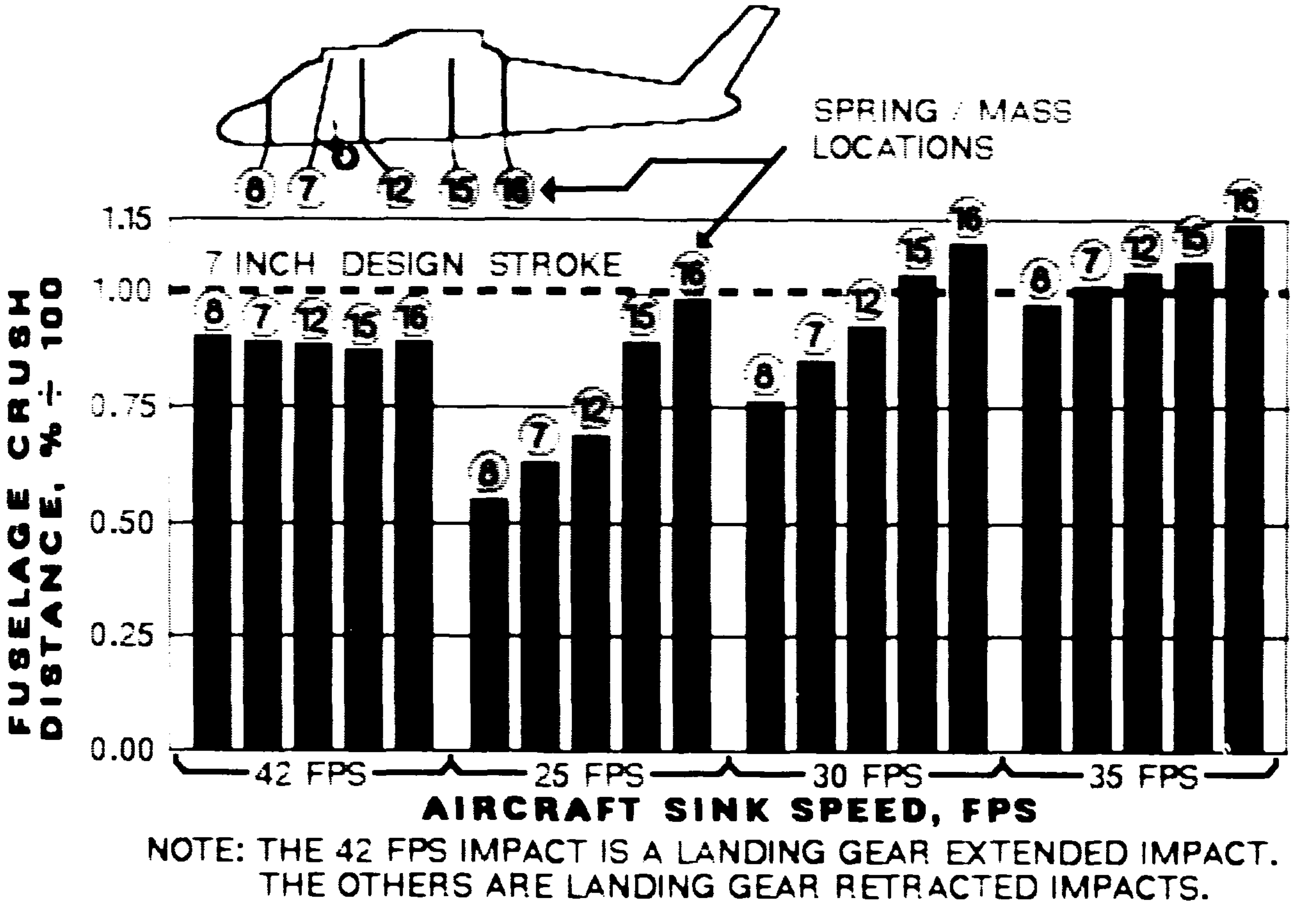


Figure 58. Comparison of fuselage deformation with and without the coupled landing gear extended for 0-degree roll and 0-degree pitch for Phase II study.

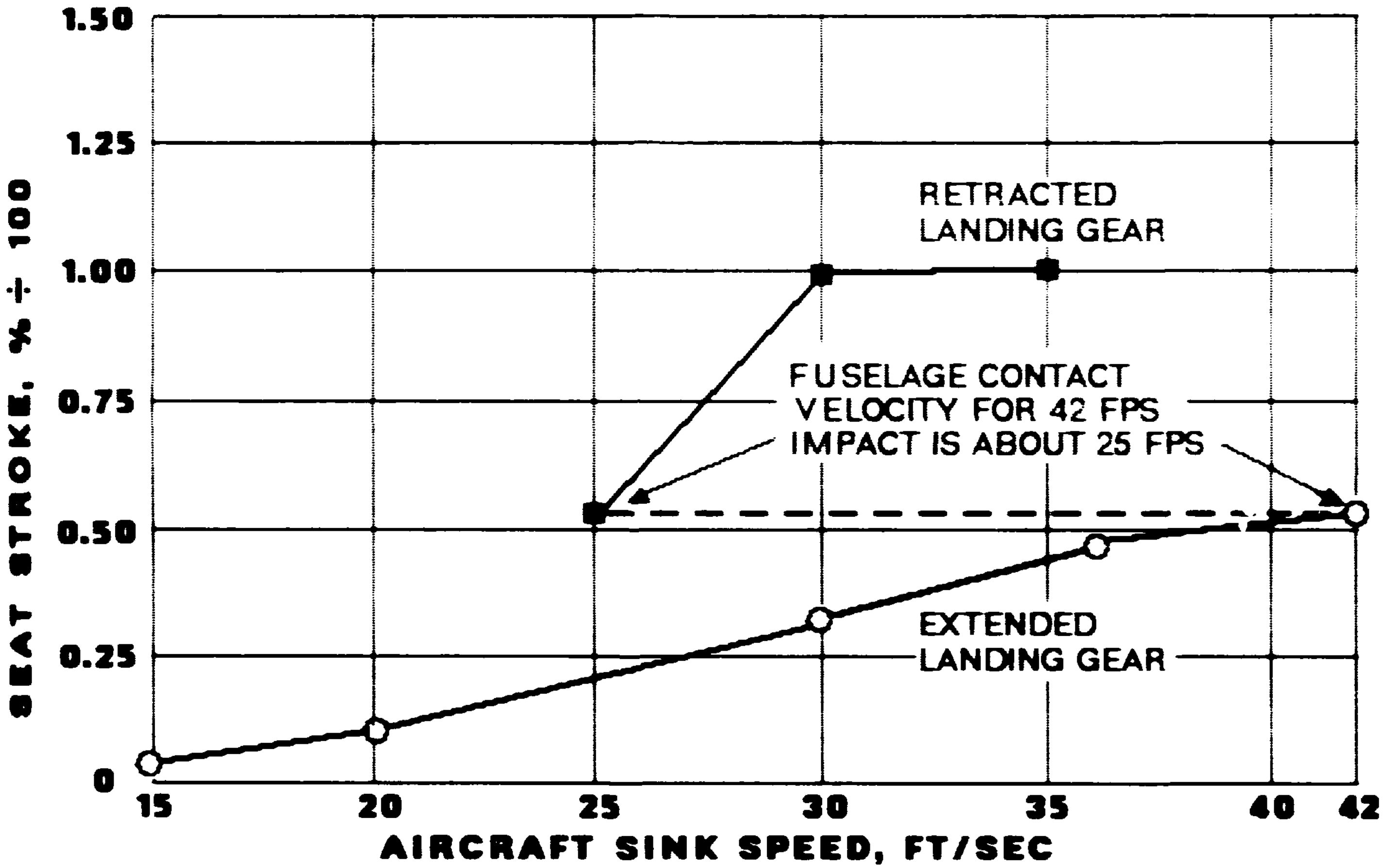


Figure 59. Envelope of occupant seat strokes for coupled landing gear extended and retracted in Phase II study.

TABLE 15. OCCUPANT RESPONSE AND SEAT STROKES IN PHASE II STUDY WITH COUPLED LANDING GEAR EXTENDED (STROKES IN INCHES)

AIRCRAFT IMPACT ATTITUDE, DEG.		AIRCRAFT IMPACT VELOCITY AND OCCUPANT RESPONSE																			
		42 fps				36 fps				30 fps				20 fps				15 fps			
		SEAT STROKE		DRI		SEAT STROKE		DRI		SEAT STROKE		DRI		SEAT STROKE		DRI		SEAT STROKE		DRI	
ROLL	PITCH	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW
0	-5	6.3	6.3	17.0	17.0	5.1	5.1	15.8	15.8	3.2	3.2	15.0	15.0	0.7	0.7	10.2	10.2	0.3	0.3	8.4	8.4
0	0	5.6	5.6	17.7	17.7	6.9	6.9	18.1	18.1	3.6	3.6	15.3	15.3	0.7	0.7	10.7	10.7	0.3	0.3	8.9	8.9
0	7.5	6.5	6.5	20.8	20.8	6.7	6.7	19.4	19.4	3.8	3.8	17.7	17.7	1.5	1.5	12.2	12.2	0.3	0.3	9.4	9.4
0	15	7.6	7.6	20.4	20.4	7.0	7.0	19.7	19.7	4.6	4.6	16.8[a]	16.8[a]	2.1	2.1	18.2	18.2	0.4	0.4	9.3	9.3
5	-5	7.5	6.7	16.8	17.6	4.6	4.5	15.5	15.6	3.0	2.7	14.6	14.7	0.4	0.5	10.0	9.0	0.1	0.1	8.1	7.0
5	0	6.5	5.6	16.8	16.8	5.6	5.9	17.7	17.8	3.2	2.8	18.5	17.7	0.3	0.2	10.3	8.8	0.2	0.1	8.2	7.0
5	7.5	6.1	6.5	19.8	19.8	5.8	5.2	18.4	17.9	3.2	3.0	18.6	17.6	1.0	0.9	11.0	9.5	0.2	0.1	7.8	6.1
5	15	7.2	6.7	19.4	19.5	5.8	5.8	19.2	19.7	3.2	2.9	18.7	17.8	0.8	0.9	15.3	15.1	0.7	0.6	12.0	11.6
10	5	6.3	6.4	16.7	15.0	3.4	4.2	14.7	16.8	2.0	2.3	14.7	15.9	0.2	0.2	9.0	7.6	0.1	0.1	7.6	6.5
10	0	5.2	6.0	15.7	16.3	4.1	5.6	17.5	19.0	2.8	2.8	17.5	17.4	0.3	0.3	9.2	8.7	0.2	0.1	8.3	7.3
10	7.5	5.4	6.2	18.6	18.2	4.7	4.6	18.7	18.8	2.2	2.0	17.5	16.7	0.6	0.3	11.8	10.2	0.2	0.1	8.9	7.1
10	15	5.6	5.2	18.6	18.1	3.4	3.8	18.8	19.4	2.9	2.4	18.7	18.0	0.6	0.3	14.2	12.5	0.3	0.2	10.3	8.3
15	5	7.2	6.5	15.8	15.5	3.4	3.8	15.8	17.0	1.8	1.4	14.4	13.6	0.2	0.1	9.9	7.9	0.1	0.1	7.6	6.4
15	0	5.5	5.8	15.5	16.8	3.9	4.6	17.5	18.6	2.0	1.6	15.9	14.9	0.3	0.2	11.2	9.0	0.2	0.1	8.1	6.8
15	7.5	4.0	4.3	17.5	18.0	3.0	2.6	17.3	17.2	1.9	1.3	16.2	14.3	0.4	0.3	11.6	8.5	0.2	0.2	8.7	6.5
15	15	6.3	4.3	19.1	17.8	2.4	1.5	17.6	14.7	1.9	0.9	17.0	14.1	0.4	0.2	12.2	9.4	0.2	0.1	8.7	6.5

[a]DRI DID NOT REACH A PEAK. PEAK VALUES ARE EXPECTED TO BE LESS THAN 19.

TABLE 16. OCCUPANT RESPONSE AND SEAT STROKES IN PHASE II STUDY WITH COUPLED LANDING GEAR RETRACTED (STROKES IN INCHES)

AIRCRAFT IMPACT ATTITUDE, DEG.		AIRCRAFT IMPACT VELOCITY AND OCCUPANT RESPONSE											
		35 fps				30 fps				25 fps			
		SEAT STROKE		DRI		SEAT STROKE		DRI		SEAT STROKE		DRI	
ROLL	PITCH	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW	LEFT SEAT	RIGHT SEAT	LEFT CREW	RIGHT CREW
0	-5	14.2	14.2	33.8	33.8	11.6	11.6	20.2	20.2	5.9	5.9	19.6	19.6
0	0	14.2	14.2	22.8	22.8	9.7	9.7	21.1	21.1	6.5	6.5	20.9	20.9
0	7.5	14.1	14.1	38.8	38.8	11.1	11.1	20.3	20.3	6.2	6.2	19.4	19.4
0	15	14.0	14.0	36.0	36.0	12.5	12.5	17.8	17.8	6.2	6.2	18.1	18.1
5	-5	14.1	14.2	36.7	26.1	12.9	11.0	20.2	19.9	7.9	6.5	19.8	19.7
5	0	14.1	14.1	36.8	23.0	12.2	10.2	20.4	20.5	6.7	6.0	20.2	20.2
5	7.5	14.1	14.1	34.9	30.4	11.6	10.9	19.4	19.7	5.6	5.5	19.0	19.2
5	15	14.1	14.1	29.6	24.6	12.0	9.9	17.5	17.4	7.7	5.0	17.4	17.2
10	-5	14.1	13.7	36.0	20.9	12.8	9.9	19.9	19.7	7.8	5.7	19.8	19.6
10	0	14.0	13.9	36.5	20.8	14.0	10.5	19.8	19.5	7.8	5.6	19.4	19.0
10	7.5	14.1	13.7	26.2	19.6	9.1	8.6	17.8	18.5	3.3	3.3	16.5	16.9
10	15	14.1	13.5	27.2	18.3	11.6	8.7	17.1	17.2	5.6	4.0	16.6	15.9
15	-5	14.0	12.7	32.1	19.4	12.5	9.1	19.6	19.3	7.6	5.3	19.5	19.3
15	0	14.1	11.3	30.3	18.7	12.1	7.2	19.2	18.8	7.3	3.8	19.1	18.4
15	7.5	11.9	9.7	17.1	16.4	5.9	4.7	16.6	16.1	1.8	1.3	14.3	12.7
15	15	14.0	12.5	20.3	16.7	10.6	7.9	16.7	16.8	4.9	3.3	15.8	15.0

The nose strikes occurred primarily for impacts at higher pitch angles. When the aircraft strikes the tail landing gear, the reaction load from the tail gear imparts a pitching acceleration to the aircraft. This causes the aircraft to roll onto and over the main landing gear, resulting in the nose strike. As seen in Table B-4, most of the strikes, represented by the deformations of Springs 8 and 8', are insignificant. However, the four strikes representing impact at +15 degrees pitch require special attention when designing a fuselage. The pitching phenomenon is a characteristic of tailwheel-type landing gear configurations because of the large moment arm between the tail landing gear and the aircraft cg. The KRASH analysis has identified a possible impact phenomenon that can now be used to aid in the design of the forward section of aircraft.

The occupant injuries that occurred at sink speeds of 35 fps, with the landing gear retracted, are a result of the crew seat bottoming out. As seen in Table 16, the DRI's in some cases are in excess of 30, which represents a probability of over 50 percent for spinal injury. In comparing the fuselage deformations for the three sink speeds with the landing gear retracted and for 42 fps with the landing gear extended, as shown in Figure 58, the impact at 35 fps is definitely more severe on the fuselage than the 42 fps impact.

The fuselage capability to absorb energy was designed for an impact between 25 and 27 fps, which is also evident in Figure 58. All the other conditions, with the gear extended and for sink speeds of 25 and 30 fps with the gear retracted, yielded occupant DRI's that were equal to, or less than, 21. These DRI's are consistent with the DRI's predicted for a trapezoidal pulse with a 14.5g peak acceleration. This correlation is shown in Figure 60.

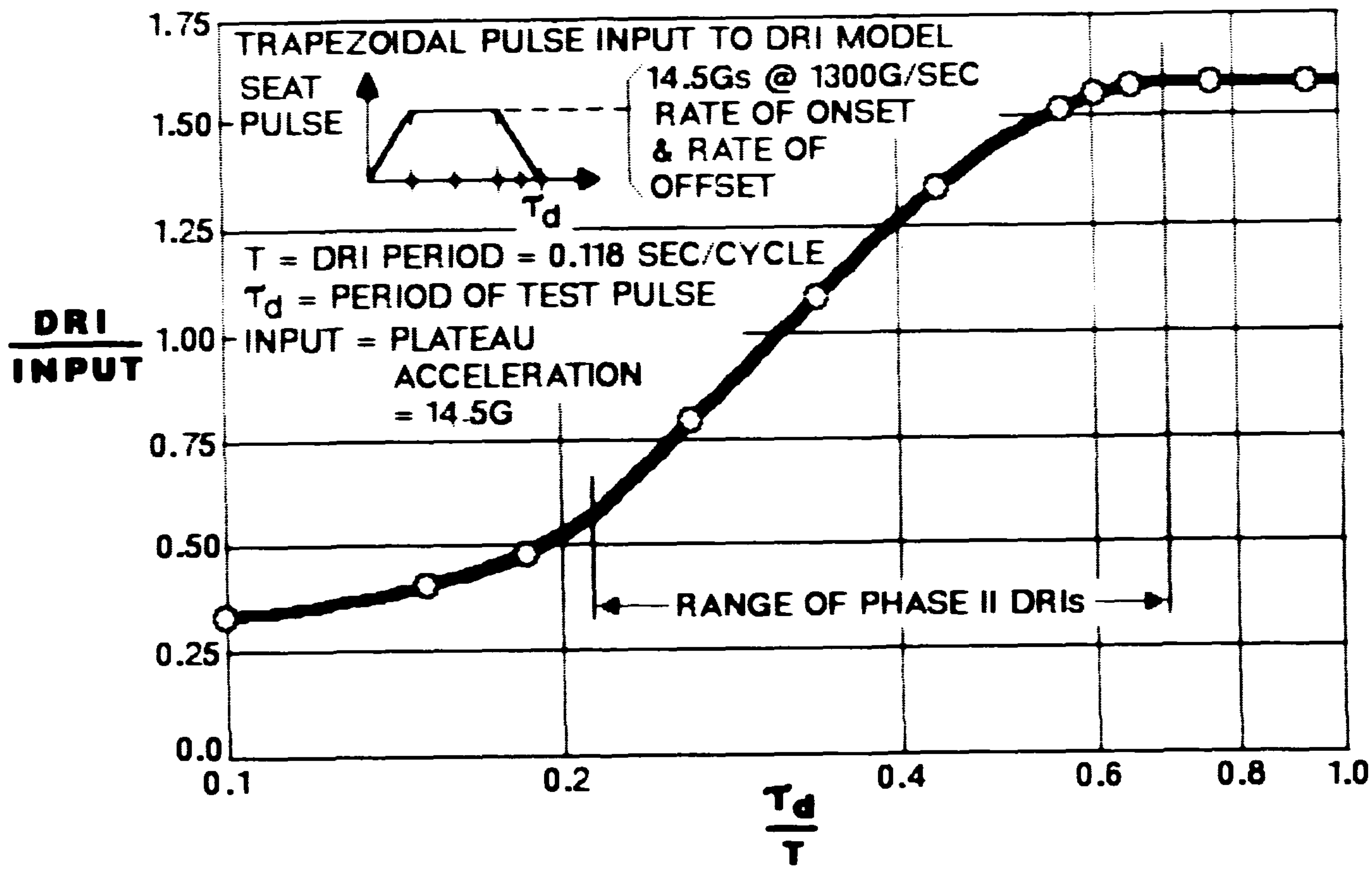


Figure 60. DRI as a function of pulse shape and duration with range of DRI values in Phase II study of coupled landing gear.

SECTION 5

'KRASH' ANALYSIS WITH UNCOUPLED LANDING GEAR

5.1 GENERAL

The results of the KRASH analysis described in Section 4 concentrated on a configuration of the crashworthy landing gear with two trailing arms of the main landing gear coupled with a torque tube. Additional KRASH analyses were conducted in Phase I of the program to determine the effect of an uncoupled landing gear on the strokes of the main landing gears and the crew seats. The differences in the strokes of these components for coupled and uncoupled landing gears are shown in Figures 32 and 44.

The coupled landing gear was chosen for the crashworthy designs because of its efficacy in absorbing energy in high roll impacts as demonstrated in Phase I studies. If the roll impact conditions were relaxed, the landing gear could be uncoupled and the fuselage designed to absorb a greater portion of the crash impact energy. It is evident that the need for landing gear coupling becomes less and less necessary as the roll angle during impact is decreased. The KRASH analyses of the uncoupled landing gear were conducted with the gear extended to determine the trade-off in incremental weight in the landing gear and in the fuselage, with and without gear coupling, respectively, for identical impact conditions.

The KRASH analyses of uncoupled landing gear were conducted for a sink speed of 42 fps at 0 degree pitch for 5, 10, and 15 degrees roll. For 0 degree roll, the results for coupled and uncoupled landing gears are identical. Only the 0 degree pitch impact condition was investigated because this impact is considered to be severest for a fuselage with an uncoupled landing gear.

5.2 KRASH MODEL OF UNCOUPLED LANDING GEAR

The KRASH model for the uncoupled landing gear is identical to the Phase II refined model described in Section 4.4 and shown in Figures 45 and 46, but with the following exceptions:

a. The torque tube was uncoupled by reducing its torsional moment of inertia to zero

b. The landing gear stroke was uninhibited

c. The fuselage was allowed infinite stroke

The keel beams, the primary energy-absorbing components in the fuselage, were modeled for infinite stroke in order to simplify the modification to the existing KRASH model. The fuselage deflections for the uncoupled landing gear, therefore, exceed the depth of 9 inches designed for the underfloor structure. Since the deflections are merely used to calculate the weight increments of the fuselage, the increase in the required underfloor depth is insignificant to the design. For detail design, the existing keel beam can be replaced by several other keel beam designs identified in Reference 4 and identified by their parameters in Figure 61. The existing keel beam is identified as No. 4 in the figure. Several designs of higher specific energy can be chosen to accommodate the required 9-inch depth of the underfloor structure.

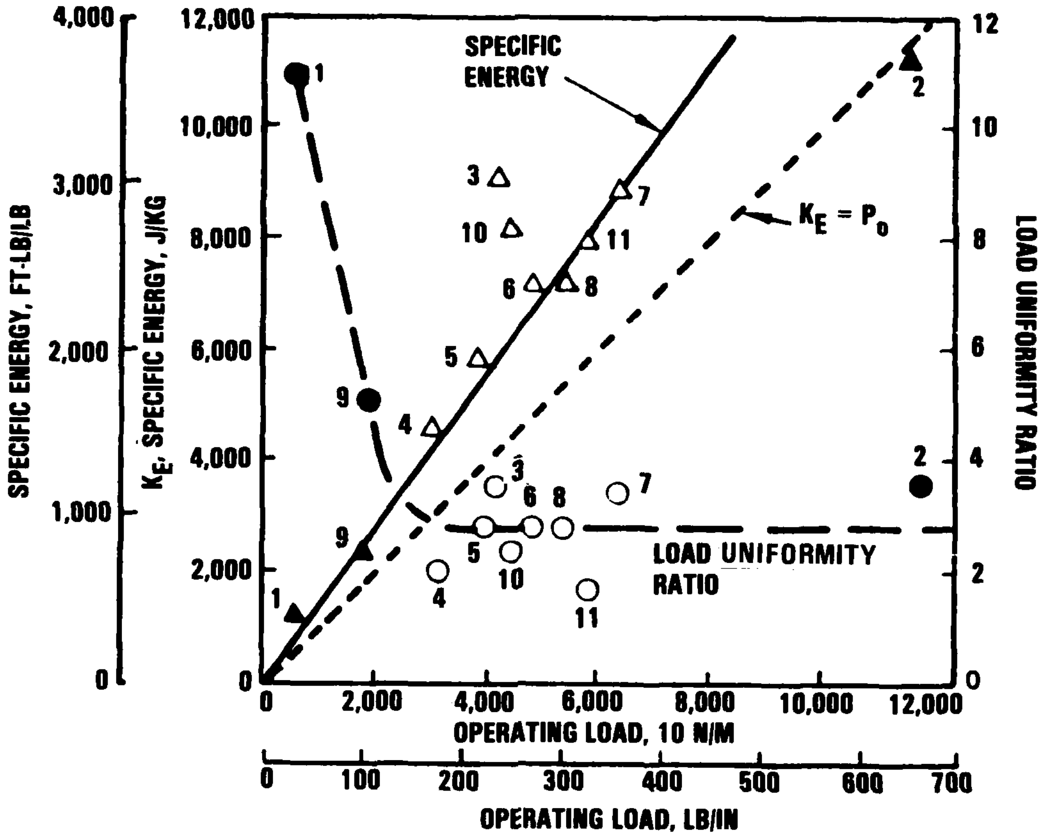
5.3 KRASH ANALYSIS RESULTS OF UNCOUPLED LANDING GEAR

The KRASH analyses of the uncoupled landing gear in the extended position were conducted for a sink speed of 42 fps at impact attitudes of 5, 10, and 15 degree roll and 0 degree pitch for all cases. The roll angle in the analyses was to the left. Therefore, the left gear was the down-side gear and the right gear the up-side gear. Consequently, the largest deflections in the landing gear, fuselage and seat occurred on the left side.

Under impact, the main landing gear strokes increase with roll angle. The strokes of the uncoupled gear are 2.3 to 3.0 inches longer than those of the coupled gear. The landing gear strokes and the seat strokes are given in Table 17. The maximum stroke of 23.7 inches occurs for 15 degree roll impact, whereas the maximum available stroke is 24 inches. The strokes of the coupled and uncoupled main landing gears are compared in Figure 62. The strokes of both the down-side and up-side gears are shown.

The seat strokes for the uncoupled landing gear also increase with roll angle. The maximum seat stroke is 11.9 inches, where 14 inches is the maximum available stroke. The maximum seat stroke is 6.4 inches greater than that for the coupled landing gear. The strokes of the down-side seat for the coupled and uncoupled landing gears are compared in Figure 63. Noting that the KRASH analysis models a 50th percentile occupant, the maximum available seat stroke may be exceeded if a heavier occupant is modeled for the uncoupled landing gear.

The deflections of the down-side fuselage springs for the coupled and uncoupled landing gears are given in Table 18. The maximum deflections of the springs in the nose, mid and tail regions for the uncoupled landing gear greatly exceed those for the coupled landing gear. The maximum deflections of a spring from each of the three regions are compared for the coupled and uncoupled landing gears in Figure 64. The maximum deformation in the mid-fuselage region for the uncoupled landing gear is 50 percent greater than for the coupled landing gear. This signifies a requirement of 50 percent greater energy-absorbing capacity for the fuselage with uncoupled landing gear in high roll impact conditions. This situation of increased energy absorption required in the fuselage with uncoupled landing gears was predicted by Figure 52.



NOTES:
(1) ▲ ● NO STITCHES
(2) △ ○ STITCHED
(3) SPECIMENS 10 AND 11 HAVE SKINS TAPERED WITH PLY DROP-OFF IN A CHEVRON PATTERN
(4) THE EXISTING KEEL BEAM DESIGN IS IDENTIFIED AS NO. 4
(5) SPECIFIC ENERGY = $\frac{\text{TOTAL ENERGY}}{\text{SPECIMEN WEIGHT}}$
(6) LOAD UNIFORMITY RATIO = $\frac{\text{MAXIMUM LOAD}}{\text{AVERAGE LOAD}}$
(7) OPERATING LOAD = $\frac{\text{TOTAL ENERGY}}{\text{(STROKE)} \times \text{(SPECIMEN LENGTH)}}$

Figure 61. Crashworthy design parameters of several keel beam designs.

TABLE 17. COMPARISON OF LANDING GEAR AND SEAT STROKES FOR COUPLED AND UNCOUPLED RETRACTABLE LANDING GEAR DESIGNS

Sink speed is 42 feet per second
and pitch angle is 0 degree
for all cases

Impact Roll Angle, degrees	Landing Gear	Landing Gear Strokes, inches			Seat Strokes, inches	
		Main, Down-side	Main, Up-side	Tail	Down-side	Up-side
5	Coupled	19.3	18.0	8.9	6.5	5.6
5	Uncoupled	21.6	17.6	8.9	7.9	6.4
10	Coupled	20.2	16.7	8.8	5.2	6.0
10	Uncoupled	23.1	16.7	8.7	11.8	7.9
15	Coupled	20.7	16.7	8.5	5.5	5.8
15	Uncoupled	23.7	14.6	8.3	11.9	6.6

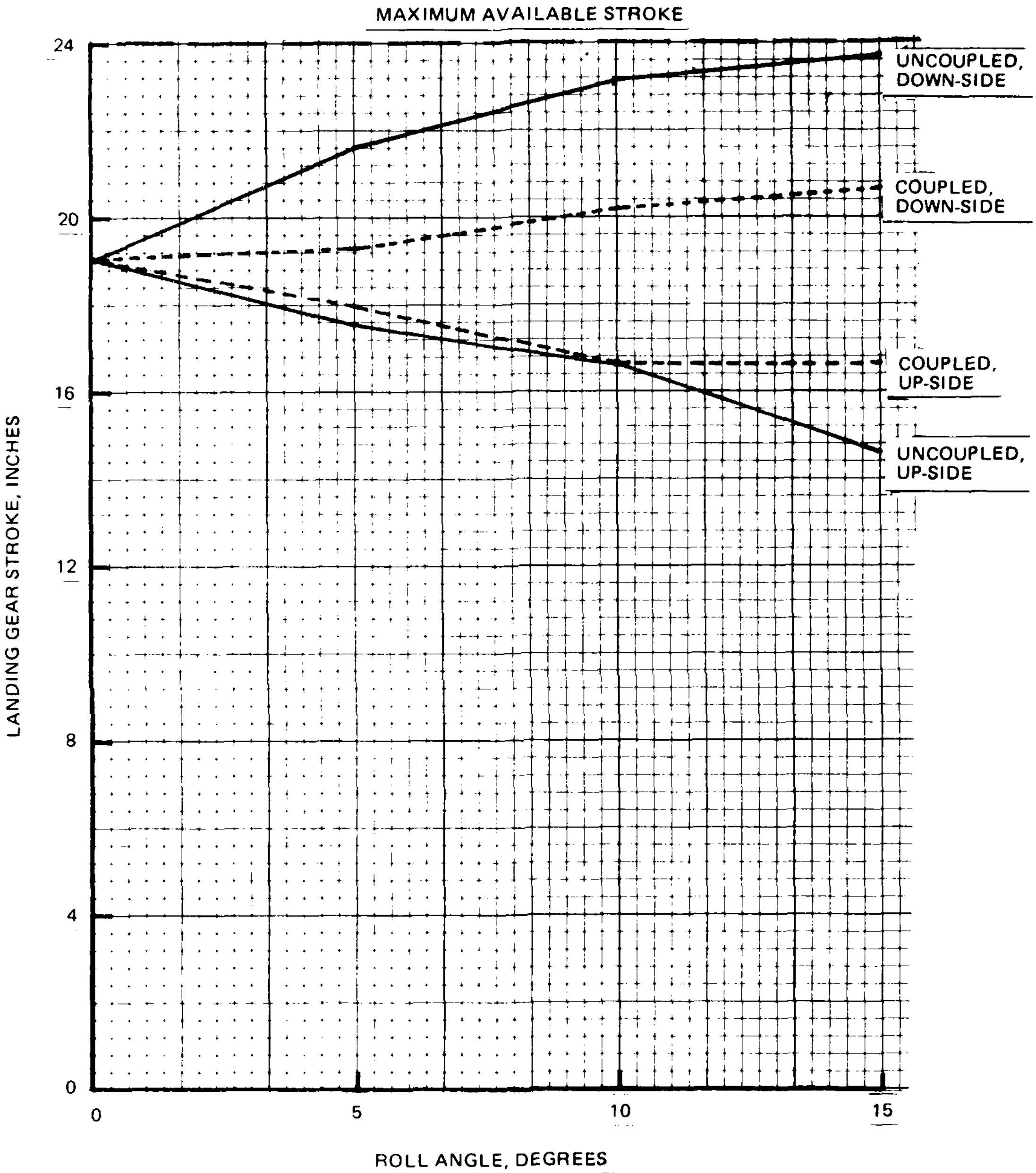


Figure 62. Comparison of the strokes of the coupled and uncoupled main landing gears for impact at 42 feet per second and 0-degree pitch.

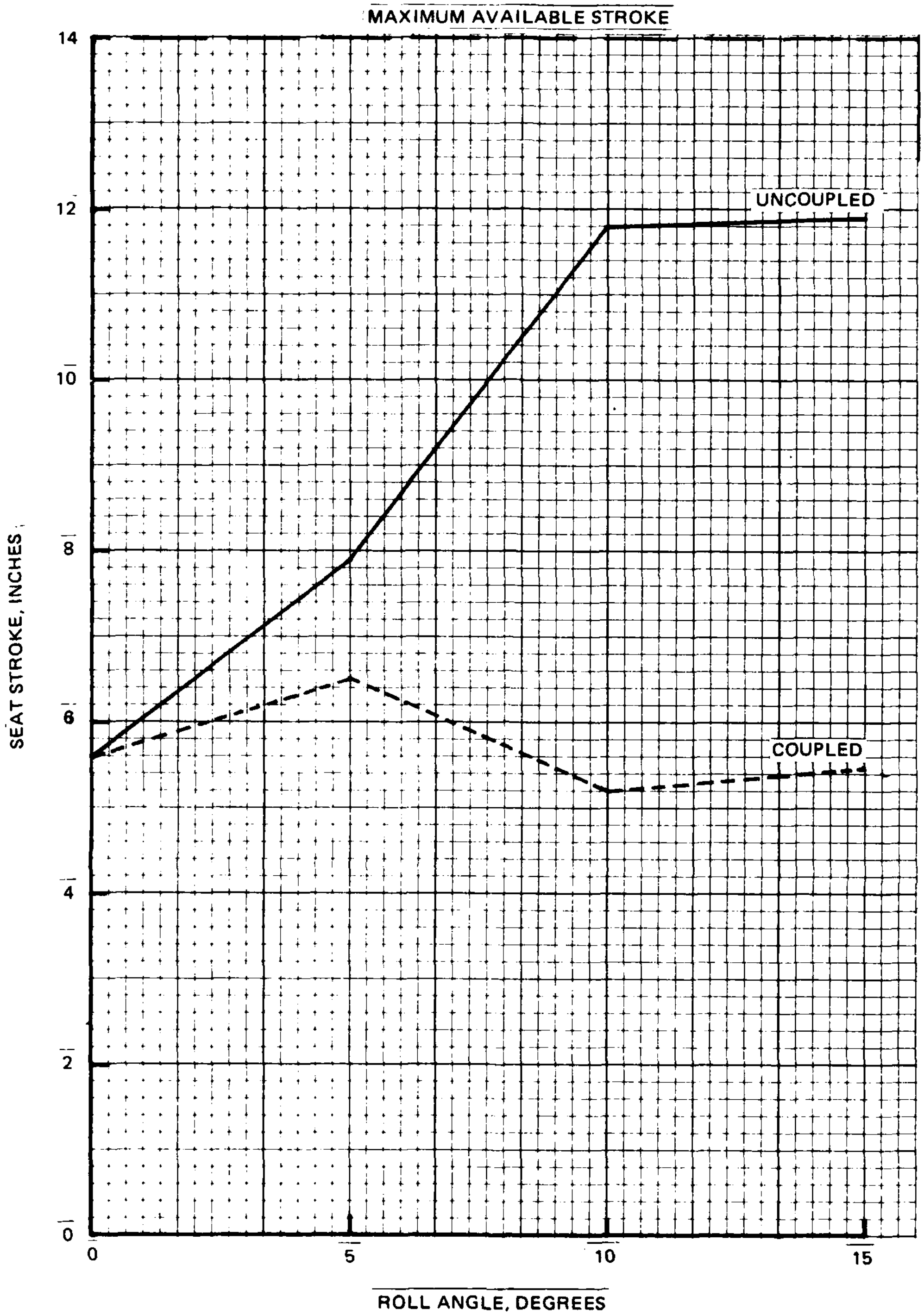


Figure 63. Comparison of the seat strokes for coupled and uncoupled retractable landing gears for impact at 42 feet per second and 0-degree pitch.

TABLE 18. COMPARISON OF FUSELAGE DEFLECTIONS FOR COUPLED AND UNCOUPLED RETRACTABLE LANDING GEAR DESIGNS

Sink speed is 42 feet per second and pitch angle is 0 degree for all cases

Impact Roll Angle, degrees	Landing Gear	Spring Deflections in Inches as Identified by Location in the Fuselage										
		Nose Region				Mid Region				Tail Region		
		1	7	8	8'	12	12'	15	15'	16	16'	18"
5	Coupled	6.66	7.26	7.15	6.70	7.23	6.64	7.32	6.71	7.26	6.86	1.55
5	Uncoupled	7.41	8.66	8.54	7.53	8.63	7.37	8.66	7.39	8.38	7.58	1.67
10	Coupled	6.32	6.94	6.76	6.36	7.02	6.34	7.46	6.64	7.52	6.98	1.66
10	Uncoupled	7.31	9.74	8.97	7.01	9.94	7.48	10.75	8.22	9.88	8.72	1.86
15	Coupled	5.72	7.18	6.88	6.10	7.38	5.73	8.21	6.30	8.16	6.93	1.06
15	Uncoupled	6.66	10.33	8.88	5.88	10.85	7.11	12.30	8.51	11.63	9.23	1.36

Notes: (1) The springs shown are on the left side of the fuselage because the roll angle at impact is to the left.

(2) The springs are identified in Figure 46.

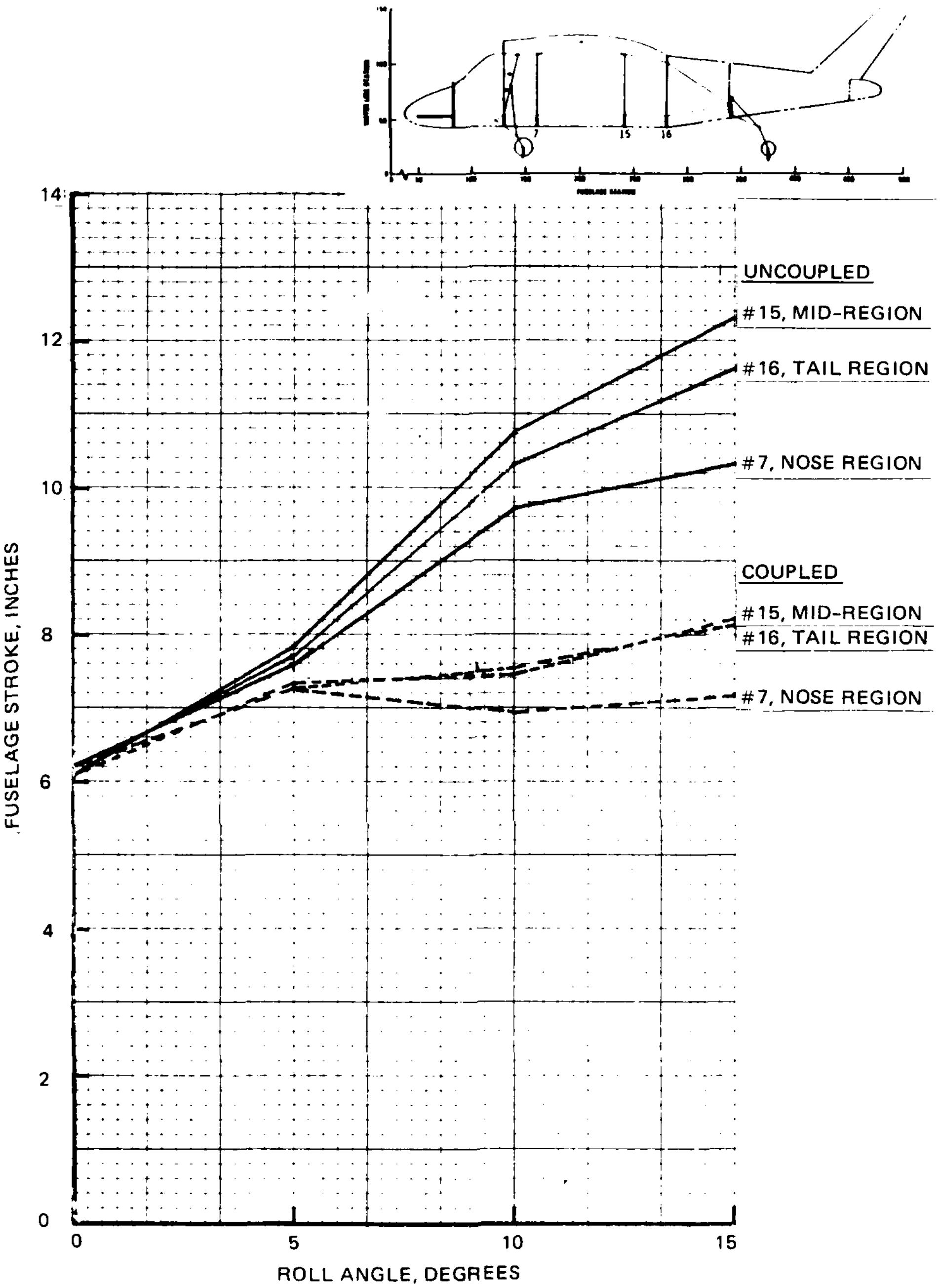


Figure 64. Comparison of the maximum spring deflections from each region of the fuselage for coupled and uncoupled retractable landing gears.

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F

5.4 DISCUSSION

The strokes and deflections of the three elements in the energy-absorbing chain of a helicopter increase with increasing angle of roll impact of a fuselage with uncoupled landing gear. The most dramatic increases are in the seat stroke and in the fuselage deformation. By uncoupling the landing gears, their requirements for absorbing energy is effectively increased. The energy not absorbed by the gears must be absorbed by the fuselage. The energy absorption requirement for the fuselage is increased by 50 percent. Additionally, the seat stroke is increased by nearly 100 percent to attenuate the acceleration levels to survivable limits.

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SECTION 6

WEIGHT SENSITIVITY ANALYSIS

6.1 APPROACH

The weight sensitivity analysis consists of calculating the required increment in weights of each of the three elements in the helicopter's energy-absorbing system for every crash-impact condition to be survivable. The three elements are the main and tail landing gears, the fuselage and the crew seat. There are 134 crash-impact conditions:

- 86 conditions are with the gear extended for 5 sink speeds, 4 roll angles and 4 pitch angles
- 48 conditions are with the gear retracted for 3 sink speeds, 4 roll angles and 4 pitch angles

Of these 134 conditions, 128 conditions were investigated with the coupled landing gear. An additional 6 conditions were investigated for the uncoupled landing gear with 0 degree pitch angle and 5, 10 and 15 degree roll angles. The required weight increments were tabulated into weight trend tables from which weight trend curves were plotted.

The results of the 80 analyses for the extended crashworthy retractable landing gear were used for calculating the weight increments of the crashworthy fixed landing gear. The fixed gear is 41 pounds lighter than the retractable gear, and the difference of 0.4 percent in gross weight has negligible effect on the crash-impact behavior of the helicopter. The crash-impact behavior, represented by the deformations and strokes of the energy-absorbing elements of the helicopter, determine the weight increments.

The weight increments are calculated by first sizing the components based on the loads and deflections from KRASH analyses and on the loads from static structural analysis. The weights of the components are then calculated and the increment determined with respect to the standard (noncrashworthy) helicopter. To make the weight trend curves for the crashworthy coupled and uncoupled landing gears comparable with one another and with respect to the standard gear, landing gears made of 300M alloy steel are first discussed. The reduction in weight that can be gained by using composite materials is discussed separately in Section 3.10 to emphasize the advantages gained by their application.

6.2 SIZING AND WEIGHTS WITH COUPLED LANDING GEAR

The landing gear, fuselage and crew seat were sized according to the load and deformation necessary to absorb the desired crash-impact energy. The weights of the components were then calculated from their sizes. The maximum possible increase in system weight for crashworthiness is 654 pounds, the component breakdown of which is shown in Table 2.

6.2.1 Coupled Landing Gear

The crashworthy main landing gear was sized for the shock strut, the trailing arm and the torque tube. The shock strut was sized on the basis of the impact velocity, which determines the strut load. With negligible influences of roll and pitch angles, a single strut geometry was designed for all conditions of each impact velocity.

At impact, ground reaction loads at the wheels force the trailing arm to deflect by pivoting about the torque tube center line. The resistance to motion is provided by a practically constant shock strut load. The geometry of, and the loads on, the trailing arm are shown in Figure 65. The critical load for each impact condition, sixteen attitudes for each of five impact velocities, was determined as the maximum load occurring at any one of several incremental positions of the wheel center line with respect to the pivot axis. The trailing arm is sized to react the critical load.

The torque tube loads are the torsional loads determined from KRASH analysis, and bending moments and shear loads determined from static structural analysis. The torsional loads are taken from KRASH analysis because high inertial loading is encountered in the torsional direction. The characteristic load distribution in the torque tube depends on the roll angle attitude with the pitch angle having a negligible effect and the impact velocity determining the magnitude of the load. Based on these conditions, the torque tube was sized for each of the conditions. In addition, a minimum weight torque tube, sized for normal ground handling conditions, was found to be more severe than even the 42 fps, 0-degree roll condition. This is mainly because there is no torsional load during 0 degree roll.

The trailing arm and shock strut of the tail gear were sized from loads calculated with static structural analysis. The method of sizing is similar to that used for the main landing gear.

The breakdown in weights of the components of crashworthy and standard landing gears is given in Table 4. The weights for the retractable and fixed crashworthy gears represent the condition for the severest impact. The crashworthy retractable gear is 262 pounds heavier than the standard retractable gear and 41 pounds heavier than the crashworthy fixed gear.

6.2.2 Fuselage

Initial sizing of the fuselage allocated 9 inches to the floor substructure as the energy-absorbing crush zone with approximately 70 percent of that stroke

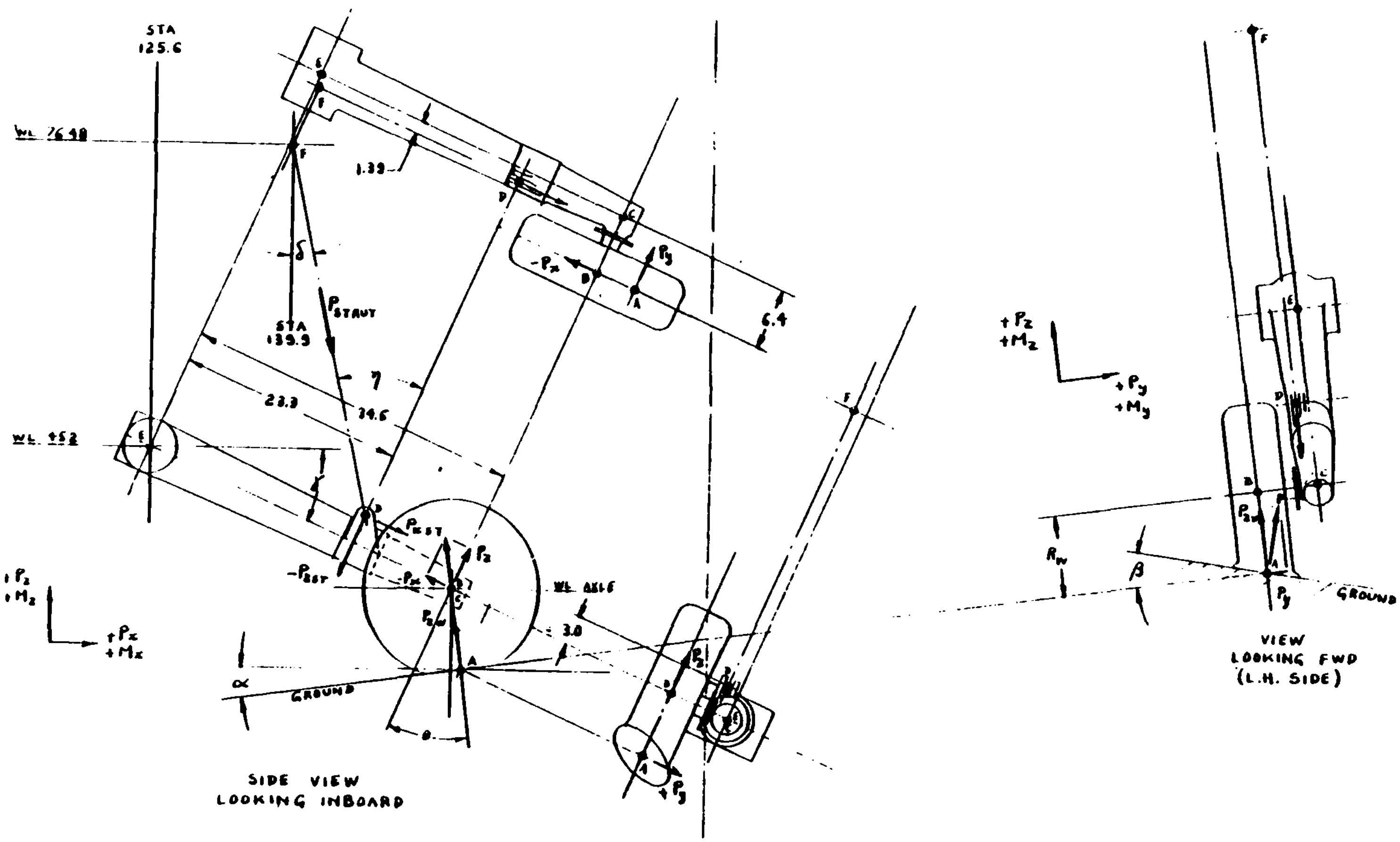

Figure 65. Geometry of coupled main landing gear for sizing of the trailing arms.

effective. This was the estimated stroke required to attenuate the remaining energy of a 42 fps impact after fuselage contact. The full stroke was utilized at the impact velocity of 42 fps for -5 and 0 degree pitch angles and for all roll angles. However, the full stroke was not utilized over the entire fuselage length. This indicated that a weight savings could be achieved by judiciously selecting keel beam geometry according to the desired energy to be absorbed, as evidenced by the deformation undergone by the fuselage.

The minimum depth of the underfloor structure required for basic structural support determines the minimum weight fuselage configuration. The minimum depth, using the same underfloor structure, was determined to be 3 inches. The remaining 6 inches of underfloor structure, or a maximum of 57 pounds, was adjusted according to the energy to be absorbed.

To optimize the design, because of the variation in the stroke along the fuselage length, the fuselage was divided into the nose, mid and tail regions. For each region, the maximum stroke utilized, according to KRASH analysis, would determine the required depth of the underfloor structure for that region. The weights of the three regions were apportioned as 25, 60, and 15 percent for the nose, mid and tail regions, respectively. This division is shown in Figure 66.

In addition to the weight increment associated with the underfloor depth of the fuselage, the weight of the increased structure supporting the floor was also included. This additional weight was taken to be constant for a given impact velocity (regardless of the stroke required) and varied in proportion to the strut loading.

6.2.3 Crew Seats

The crew seats were designed for a maximum stroke of 14 inches, which results in an increment in weight of 44 pounds for two seats. The seats were sized by the strokes determined from KRASH analyses based on the known behavior and geometry of the AH-64 crew seat.

6.3 SIZING AND WEIGHTS WITH UNCOUPLED LANDING GEAR

The landing gear with the torque tube was uncoupled by replacing the torque tube with a cross tube. The cross tube was designed to carry bending moments, and axial and shear loads. The trailing arms of the uncoupled landing gear, the fuselage and the crew seats were sized similarly to those for the helicopter with the coupled landing gear. The loads and deflections were determined from KRASH analyses and from structural analyses. The shock strut is unchanged from that of the coupled gear whereas the cross tube is lighter than the torque tube, as is the trailing arm. The fuselage is heavier than that for the coupled landing gear because 50 percent greater energy-absorbing capability is required. The crew seat with the longer stroke adds 5.2 pounds to the weight of the crew seat with coupled landing gear.

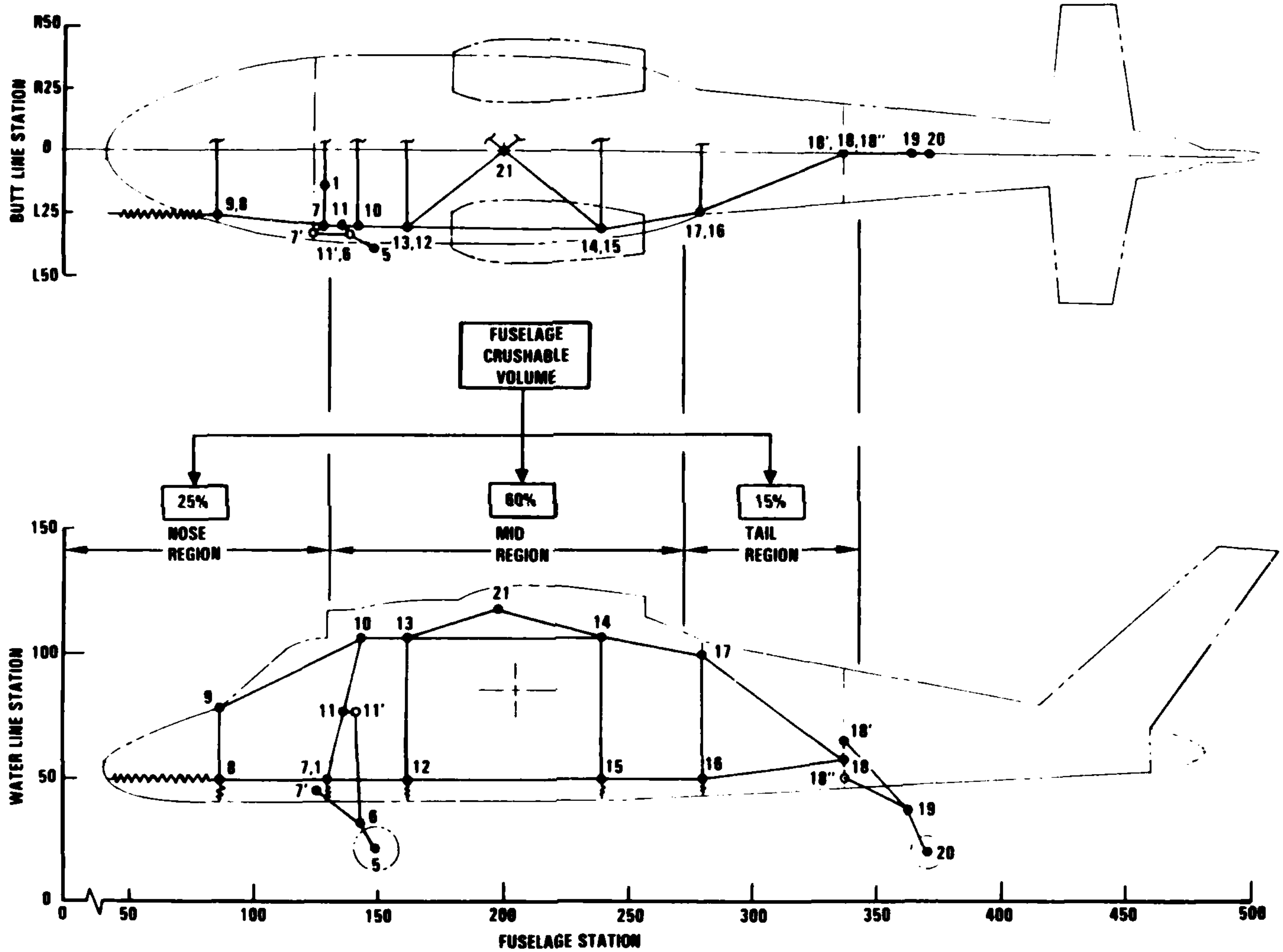

Figure 66. Sizing regions of the fuselage.

The helicopter with the uncoupled landing gear is 53 pounds lighter than the helicopter with the coupled landing gear for the most severe crash-impact condition as given in Table 1. If the cross tube is designed with graphite/epoxy, as explained in Section 3.10.2, the cross tube is 19 pounds lighter than the steel cross tube for the most severe crash impact. The difference in weight is reflected in the gross weight of the helicopter as shown in Table 19.

TABLE 19. COMPARISON OF MAXIMUM GROSS WEIGHTS OF CRASHWORTHY UNCOUPLED LANDING GEARS WITH AND WITHOUT COMPOSITE CROSS TUBES

Item	Helicopter Weight, Pounds	
	Uncoupled LG with Steel Cross Tube	Uncoupled LG with Gr/Ep Cross Tube
Crew (2)	500	500
Payload	1,763	1,763
Fuel	1,550	1,550
Tail Rotor	67	67
Body	1,045	1,045
Landing Gear	414	395
Exhaust	94	94
Nacelle	139	139
Fuel System	284	284
Armor	230	230
Furnishing	308	308
Mission Equipment	919	919
Common Weight	2,634	2,634
Gross Weight	9,947	9,928

Note: Both landing gear designs are retractable.

6.4 WEIGHT TREND TABLES

The result of calculating the weights of each element of the energy-absorbing system of the helicopter has been tabulated for each condition. The incremental weights, the total weight increase and the percent increase over the gross weight of the baseline standard helicopter are given in Tables 20 through 28. The breakdown of the weights of the components of the standard helicopter, and those of its landing gear, are given in Tables 1 and 4. The weight trends for the helicopter with coupled landing gear in the extended position (retractable and fixed gears) for five impact velocities are given in Tables 20 through 24. The weight trends for three impact velocities with the gear retracted are given in Tables 25 through 27. Since the choice of landing gear for a given impact velocity is unimportant when the gear is retracted, the upper and lower limits of the increase in weight have been shown using the lightest and heaviest landing gear for the given impact velocity. The weight trends for the helicopter with uncoupled landing gear in the extended position for 42 fps impact velocity are given in Table 28. The case for the uncoupled landing gear has been studied for all roll conditions for only 0 degree pitch at impact.

The incremental weights of the crew seats, fuselage structure and landing gear are shown in Columns 3 to 12 of Tables 20 to 28. The "constant additional weight" of 243.0 shown in Column 17 is the balance of the weight in Table 2 if the weights of the landing gear, fuselage structure and crew seats are subtracted.

The additional weight required to meet the crashworthiness requirements increases with sink speed and roll angle for all cases. Though the influence of pitch angle is clear from the occupant-response point of view, its influence is obscure from the weights point of view. With the gear extended, the weight increases with increasing pitch angle at impact velocities of 42 and 36 fps. At lower impact velocities with the gear extended and at impact velocities investigated with the gear retracted, a particular trend of the influence of pitch angle cannot be specified.

6.5 WEIGHT TREND CURVES

The data from the weight trend tables are plotted to form the weight trend curves. The weight trend curves provide a graphic illustration of the trends in, and the parametric influences on, the increases in weight to meet crashworthiness requirements.

6.5.1 Coupled Retractable Landing Gear in Extended Position

The percentage increases in gross weight with respect to roll angle for the five sink speeds of the coupled retractable landing gear in the extended position are plotted in Figures 67 through 71. The discontinuity in the curves at 5 degree roll angle is due to the incorporation of the torque tube. As discussed in Section 3.3, the torque tube allows 5 degrees of uncoupled rotation. For roll-impact angles greater than 5 degrees, the weight of the torque tube increases dramatically because it transmits half the crash loads from the down-side to the up-side landing gear. For all sink speeds, the weight increases linearly. The

TABLE 20. WEIGHT TREND TABLE FOR CRASH IMPACT AT 42 FPS WITH COUPLED LANDING GEAR IN THE EXTENDED POSITION

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAILING ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED		RETR'D	FIXED	RETR'D	FIXED
0	-5	36.8	105.0	0	7.8	63.0	41.3	14	21	10	2	236.6	213.9	2.53	2.29	243.0	479.6	456.9	5.13	4.89
0	0	36.2	103.2	0	7.8		42.0					234.2	212.2	2.50	2.27		477.2	455.2	5.11	4.87
0	+7.5	37.0	81.4	0	7.8		46.5					213.2	195.7	2.28	2.09		456.2	438.7	4.88	4.69
0	+15	38.1	69.1	0	7.8		45.0					202.0	183.0	2.16	1.96		445.0	426.0	4.76	4.56
<5	-5	37.9	105.0	0	32.8		43.6					263.5	242.3	2.79	2.58		505.7	485.3	5.38	5.17
<5	0	37.0	105.0	0			42.4					261.8	240.2	2.78	2.55		504.8	483.2	5.38	5.15
<5	+7.5	37.0	97.9	0			44.4					254.7	235.1	2.71	2.50		497.7	478.1	5.31	5.10
<5	+15	37.6	91.9	0			43.5					249.3	228.8	2.65	2.43		492.3	471.8	5.25	5.03
5	-5	37.9	105.0	46.3			43.6					309.0	288.6	3.29	3.07		552.0	531.6	5.89	5.67
5	0	37.0	105.0	51.6			42.4					313.4	291.8	3.34	3.11		555.4	534.8	5.94	5.70
5	+7.5	37.0	97.9	58.6			44.4					313.3	293.7	3.34	3.13		556.3	536.7	5.93	5.72
5	+15	37.6	91.9	70.6			43.5					319.9	299.4	3.41	3.19		562.9	542.4	6.00	5.79
10	-5	36.9	105.0	82.2			45.5					342.9	325.4	3.66	3.46		586.9	568.4	6.26	6.06
10	0	36.6	105.0	86.8			44.8					348.2	329.0	3.71	3.50		591.2	572.0	6.31	6.10
10	+7.5	36.7	89.6	98.0			43.7					344.1	323.8	3.66	3.45		587.1	566.8	6.26	6.05
10	+15	36.1	91.5	106.9			44.0					354.3	334.3	3.77	3.58		597.3	577.3	6.37	6.18
15	-5	37.7	105.0	118.1			45.9					380.6	362.5	4.06	3.86		623.6	605.5	6.65	6.46
15	0	36.3	105.0	122.0			46.0					383.1	365.1	4.08	3.89		626.1	608.1	6.68	6.49
15	+7.5	35.0	92.9	137.4			42.4					385.1	363.5	4.10	3.87		628.1	606.5	6.70	6.47
15	+15	36.8	92.2	143.1	32.8	63.0	43.7	14	21	10	2	391.9	371.6	4.18	3.96	243.0	634.9	614.6	6.78	6.56

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TABLE 21. WEIGHT TREND TABLE FOR CRASH IMPACT AT 36 FPS WITH COUPLED LANDING GEAR IN THE EXTENDED POSITION

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAILING ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED		RETR'D	FIXED	RETR'D	FIXED
0	-5	35.7	67.3	0	5.6	59	28.7	14	21	10	2	192.1	[illegible].8	2.05	1.71	243.0	435.1	403.8	4.65	4.31
0	0	37.4	60.3	0	5.6		28.5					186.6	155.3	1.99	1.66		429.6	398.3	4.59	4.25
0	+7.5	37.2	49.0	0	5.6		31.4					174.8	146.2	1.86	1.56		417.8	389.2	4.46	4.16
0	+15	37.5	55.7	0	5.6		29.9					181.8	151.7	1.94	1.62		424.8	394.7	4.54	4.21
<5	-5	35.2	74.1	0	28.8		30.9					221.1	192.0	2.36	2.05		464.2	435.0	4.96	4.65
<5	0	36.5	73.0	0			30.8					221.3	192.1	2.37	2.06		464.3	435.1	4.97	4.65
<5	+7.5	36.4	59.9	0			32.0					208.1	180.1	2.23	1.93		451.1	423.1	4.83	4.53
<5	+15	36.4	61.6	0			31.0					209.8	180.8	2.24	1.93		452.8	423.8	4.84	4.53
5	-5	35.2	80.7	43.0			30.9					270.7	241.6	2.90	2.59		513.7	484.6	5.49	5.18
5	0	36.5	73.0	46.4			30.8					267.7	238.5	2.86	2.55		510.7	481.5	5.46	5.15
5	+7.5	36.4	59.9	60.3			32.0					268.4	240.4	2.87	2.57		511.4	483.4	5.47	5.17
5	+15	36.4	61.6	67.2			31.0					277.0	248.0	2.96	2.65		520.0	491.0	5.56	5.25
10	-5	34.8	77.6	81.1			31.5					305.3	276.8	3.27	2.96		548.3	519.8	5.87	5.56
10	0	36.2	75.1	84.7			32.0					305.8	277.8	3.27	2.97		548.8	520.8	5.87	5.57
10	+7.5	35.3	62.6	99.5			30.6					309.2	279.8	3.31	2.99		552.2	522.8	5.91	5.59
10	+15	34.5	67.3	101.5			33.8					315.1	288.9	3.37	3.09		558.1	531.9	5.97	5.69
15	-5	34.5	93.7	98.8			34.0					330.8	312.8	3.63	3.35		581.8	555.8	6.22	5.95
15	0	35.2	91.1	102.6			33.6					340.7	314.3	3.65	3.36		583.7	557.3	6.24	5.96
15	+7.5	33.5	77.7	118.1			34.1					341.4	315.5	3.65	3.38		584.4	558.5	6.25	5.98
15	+15	33.3	85.4	115.2	28.8	59	33.8	14	21	10	2	346.2	319.5	3.70	3.42	243.0	589.2	562.5	6.30	6.02

TABLE 22. WEIGHT TREND TABLE FOR CRASH IMPACT AT 30 FPS WITH COUPLED LANDING GEAR IN THE EXTENDED POSITION

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAILING ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED		RETR'D	FIXED	RETR'D	FIXED
0	-5	33.9	42.1	0	3.4	53.4	19.6	14	21	10	2	156.8	122.0	1.67	1.30	243.0	399.8	365.0	4.27	3.90
0	0	34.4	40.7	0	3.4		22.2					155.9	123.7	1.66	1.32		398.9	366.7	4.26	3.92
0	+7.5	34.6	40.2	0	3.4		22.2					155.6	123.4	1.66	1.32		398.6	366.4	4.26	3.92
0	+15	35.2	46.5	0	3.4		17.6					162.5	125.7	1.73	1.34		405.5	368.7	4.33	3.94
<5	-5	33.7	44.8	0	25		21.8					180.9	148.3	1.94	1.59		423.9	391.3	4.53	4.19
<5	0	34.0	40.7	0			22.6					177.1	145.3	1.89	1.55		420.1	388.3	4.49	4.15
<5	+7.5	34.0	40.7	0			23.8					177.1	146.5	1.89	1.57		420.1	389.5	4.49	4.17
<5	+15	34.0	49.9	0			18.2					186.3	150.1	1.99	1.61		429.3	393.1	4.59	4.21
5	-5	33.7	44.8	41.5			21.8					222.4	189.8	2.38	2.03		465.4	432.8	4.98	4.63
5	0	34.0	40.7	46.4			22.6					223.5	191.7	2.39	2.05		466.5	434.7	4.99	4.65
5	+7.5	34.0	40.7	55.1			23.8					232.2	201.6	2.48	2.16		475.2	444.8	5.08	4.76
5	+15	34.0	49.9	60.3			18.2					246.6	210.4	2.64	2.25		489.6	453.4	5.24	4.85
10	-5	33.1	44.1	59.4			19.8					239.0	204.4	2.56	2.19		482.0	447.4	5.17	4.79
10	0	33.6	40.7	63.2			20.0					239.9	205.5	2.57	2.20		482.9	448.5	5.18	4.80
10	+7.5	33.0	40.7	76.0			20.6					252.1	218.3	2.70	2.34		495.1	461.3	5.30	4.94
10	+15	33.7	51.2	77.2			18.2					264.5	228.3	2.83	2.44		507.5	472.3	5.43	5.04
15	-5	32.7	46.1	77.3			20.2					258.5	224.3	2.77	2.40		501.5	467.3	5.37	5.00
15	0	32.0	40.7	80.0			19.6					255.9	221.1	2.74	2.37		498.9	464.1	5.34	4.96
15	+7.5	32.7	44.0	96.0			19.4					275.9	240.9	2.95	2.58		518.9	483.9	5.55	5.18
15	+15	32.8	51.0	94.1	25	53.4	21.4	14	21	10	2	280.9	247.9	3.01	2.65	243.0	523.9	490.9	5.60	5.25

TABLE 23. WEIGHT TREND TABLE FOR CRASH IMPACT AT 20 FPS WITH COUPLED LANDING GEAR IN THE EXTENDED POSITION

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAILING ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED		RETR'D	FIXED	RETR'D	FIXED
0	-5	23.8	31.0	0	0	42.0	0.7	7	10	5	1	108.8	66.5	1.17	0.71	243.0	351.8	309.5	3.77	3.31
0	0			0	0		0					108.8	65.8	1.17	0.70		351.8	308.8	3.77	3.30
0	+7.5			0	0		0					108.8	65.8	1.17	0.70		351.8	308.8	3.77	3.30
0	+15			0	0		0					108.8	65.8	1.17	0.70		351.8	308.8	3.77	3.30
<5	-5			0	16.8		2.4					125.6	85.0	1.35	0.91		368.6	328.0	3.95	3.51
<5	0			0			1.1					125.6	83.7	1.35	0.90		368.6	326.7	3.95	3.49
<5	+7.5			0			0.3					125.6	82.9	1.35	0.89		368.6	325.9	3.95	3.49
<5	+15			0			0					125.6	82.6	1.35	0.88		368.6	325.6	3.95	3.48
5	-5			32.4			2.4					158.0	117.4	1.70	1.26		401.0	360.4	4.30	3.86
5	0			35.9			1.1					161.5	119.6	1.74	1.28		404.5	362.6	4.33	3.88
5	+7.5			42.9			0.3					168.5	125.8	1.81	1.35		411.5	368.6	4.41	3.95
5	+15			42.9			0					168.5	125.5	1.81	1.34		411.5	368.5	4.41	3.94
10	-5			41.0			0					166.6	123.6	1.79	1.32		409.6	366.6	4.39	3.92
10	0			44.4			0					170.0	127.0	1.83	1.36		413.0	370.0	4.43	3.96
10	+7.5			53.2			0					178.3	135.8	1.92	1.45		421.8	378.8	4.52	4.05
10	+15			49.2			0					174.8	131.8	1.88	1.41		417.8	374.8	4.48	4.01
15	-5			49.7			0					175.3	132.3	1.88	1.42		418.3	375.3	4.48	4.01
15	0			52.8			0					178.4	135.4	1.92	1.45		421.4	378.4	4.52	4.05
15	+7.5			63.5			0					189.1	146.1	2.03	1.56		432.1	389.1	4.63	4.16
15	+15	23.8	31.0	55.6	16.8	42.0	1.4	7	10	5	1	181.2	139.6	1.95	1.49	243.0	424.2	382.6	4.55	4.09

TABLE 24. WEIGHT TREND TABLE FOR CRASH IMPACT AT 15 FPS WITH COUPLED LANDING GEAR IN THE EXTENDED POSITION

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAILING ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED		RETR'D	FIXED	RETR'D	FIXED
0	-5	23.8	25.0	0	0	33	0	7	10	5	1	93.8	59.8	1.00	0.64	243.0	336.8	302.8	3.60	3.24
0	0			0	0							93.8	59.8	1.00	0.64		336.8	302.8	3.60	3.24
0	+7.5			0	0							93.8	59.8	1.00	0.64		336.8	302.8	3.60	3.24
0	+15			0	0							93.8	59.8	1.00	0.64		336.8	302.8	3.60	3.24
<5	-5			0	13.6							107.4	73.4	1.13	0.76		350.4	316.4	3.73	3.36
<5	0			0								107.4	73.4	1.13	0.76		350.4	316.4	3.73	3.36
<5	+7.5			0								107.4	73.4	1.13	0.76		350.4	316.4	3.73	3.36
<5	+15			0								107.4	73.4	1.13	0.76		350.4	316.4	3.73	3.36
5	-5			19.1								126.5	92.5	1.33	0.97		369.5	335.5	3.93	3.57
5	0			21.9								129.3	95.3	1.36	1.00		372.3	338.3	3.96	3.60
5	+7.5			25.4								132.8	98.8	1.40	1.04		375.8	341.8	4.00	3.63
5	+15			34.2								141.6	107.6	1.49	1.13		384.6	350.6	4.09	3.73
10	-5			24.4								131.8	97.8	1.39	1.03		374.8	340.8	3.99	3.62
10	0			27.6								135.0	101.0	1.42	1.06		378.0	344.0	4.02	3.66
10	+7.5			34.2								141.6	107.6	1.49	1.13		384.8	350.6	4.09	3.73
10	+15			38.0								145.4	111.4	1.53	1.17		383.4	352.4	4.13	3.77
15	-5			29.0								137.2	103.2	1.45	1.08		380.2	346.2	4.05	3.68
15	0			33.3								140.7	106.7	1.48	1.12		383.7	349.7	4.08	3.72
15	+7.5			42.9								150.3	116.3	1.59	1.22		393.3	359.3	4.19	3.82
15	+15	23.8	25.0	41.7	13.6	33	0	7	10	5	1	149.1	115.1	1.57	1.21	243.0	392.1	358.1	4.17	3.81

TABLE 25. WEIGHT TREND TABLE FOR FUSELAGE IMPACT AT 35 FPS WITH LANDING GEAR RETRACTED

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAILING ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT		LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT
0	-5	44.0	80.5	0/115.2	5.6/28.8	59		14		10		213.1	351.5	2.28	3.76	243.0	456.1	594.5	4.88	6.36
0	0		105.0									237.6	376.0	2.54	4.02		480.6	619.0	5.14	6.62
0	+7.5		94.1									226.7	365.1	2.42	3.91		469.7	618.1	5.02	6.51
0	+15		75.1									207.7	346.1	2.22	3.70		450.7	589.1	4.82	6.30
<5	-5																			
<5	0																			
<5	+7.5																			
<5	+15																			
5	-5		94.6									227.2	365.6	2.43	3.91		470.2	608.6	5.03	6.51
5	0		105.0									237.6	376.0	2.54	4.02		480.6	619.0	5.14	6.62
5	+7.5		102.6									235.2	373.6	2.52	4.00		478.2	616.6	5.11	6.60
5	+15		104.8									237.4	375.8	2.54	4.02		480.4	618.8	5.14	6.62
10	-5		105.0									237.6	376.0	2.54	4.02		480.6	619.0	5.14	6.62
10	0		105.0									237.6	376.0	2.54	4.02		480.6	619.0	5.14	6.62
10	+7.5		105.0									237.6	376.0	2.54	4.02		480.6	619.0	5.14	6.62
10	+15		105.0									237.6	376.0	2.54	4.02		480.6	619.0	5.14	6.62
15	-5		105.0									237.6	376.0	2.54	4.02		480.6	619.0	5.14	6.62
15	0	44.0	104.8									237.4	375.8	2.54	4.02		480.4	618.8	5.14	6.62
15	+7.5	42.0	105.0									235.6	374.0	2.52	4.00		478.6	617.0	5.12	6.60
15	+15	43.9	93.5	0/115.2	5.6/23.8	59		14		10		226.1	364.5	2.42	3.90	243.0	469.1	607.5	5.02	6.50

TABLE 26. WEIGHT TREND TABLE FOR FUSELAGE IMPACT AT 30 FPS WITH LANDING GEAR RETRACTED

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAILING ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT		LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT
0	-5	41.8	92.1	0/96.8	3.4/25.0	53.4		14.0		10.0		214.7	333.1	2.30	3.56	243.0	457.7	576.1	4.90	6.16
0	0	40.0	98.1									218.9	337.3	2.34	3.61		461.9	580.3	4.94	6.21
0	+7.5	41.0	91.3									213.1	331.5	2.28	3.55		456.1	574.5	4.89	6.15
0	+15	42.6	82.7									206.1	324.5	2.20	3.47		449.1	567.5	4.80	6.07
<5	-5																			
<5	0																			
<5	+7.5																			
<5	+15																			
5	-5	42.9	100.5									224.2	342.6	2.40	3.66		467.2	585.6	5.00	6.27
5	0	42.3	105.0									228.1	346.5	2.44	3.71		471.1	589.5	5.04	6.31
5	+7.5	41.7	105.0									227.5	345.9	2.43	3.70		470.5	588.9	5.03	6.30
5	+15	42.1	93.6									219.2	337.6	2.34	3.61		462.2	580.6	4.94	6.21
10	-5	42.8	105.0									228.6	347.0	2.44	3.71		471.6	590.0	5.05	6.31
10	0	44.0	105.0									229.8	348.2	2.46	3.72		472.8	591.2	5.06	6.32
10	+7.5	39.5	105.0									225.3	343.7	2.41	3.68		468.3	586.7	5.01	6.28
10	+15	41.7	105.0									227.5	345.9	2.43	3.70		470.5	588.9	5.03	6.30
15	-5	42.6	105.0									228.4	346.8	2.44	3.71		471.4	589.8	5.05	6.31
15	0	42.2	105.0									228.0	346.4	2.44	3.71		471.0	589.4	5.09	6.31
15	+7.5	36.4	103.4									220.6	339.0	2.36	3.63		463.6	582.0	4.96	6.23
15	+15	40.3	105.0	0/96.8	3.4/25.0	53.4		14.0		10.0		226.6	345.0	2.42	3.69	243.0	469.6	588.0	5.02	6.29

TABLE 27. WEIGHT TREND TABLE FOR FUSELAGE IMPACT AT 25 FPS WITH LANDING GEAR RETRACTED

IMPACT ATTITUDE, DEGREES		INCREMENTAL WEIGHT CHANGES, POUND										SUB-TOTAL OF INCREMENTAL WEIGHT CHANGES, POUND		SUB-TOTAL INCREMENT AS PERCENT OF BASELINE		CONSTANT ADD'L WEIGHT FOR ALL CASES, POUND	TOTAL WEIGHT INCREASE, POUND		TOTAL INCREASE AS PERCENT OF BASELINE	
		TWO CREW SEATS	FUSE-LAGE	MAIN LANDING GEAR				TAIL GEAR												
				TORQUE TUBE	TWO TRAILING ARMS	TWO SHOCK STRUTS		TRAIL'NG ARM		SHOCK STRUT										
ROLL	PITCH					RETR'D	FIXED	RETR'D	FIXED	RETR'D	FIXED	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT		LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT
0	-5	36.4	79.3	0/80.0	2.0/20.8	47.7		14.0		10.0		189.4	288.2	2.03	3.08	243.0	432.4	531.2	4.63	5.68
0	0	37.0	79.4									190.1	288.9	2.03	3.09		433.1	531.9	4.63	5.69
0	+7.5	36.7	67.2									177.6	276.4	1.90	2.96		420.6	519.4	4.50	5.56
0	+15	36.7	69.1									179.5	278.3	1.92	2.98		422.5	521.3	4.52	5.58
<5	-5																			
<5	0																			
<5	+7.5																			
<5	+15																			
5	-5	38.3	86.9									198.9	297.7	2.13	3.18		441.9	540.7	4.73	5.78
5	0	37.2	99.1									210.0	308.8	2.25	3.30		453.0	551.8	4.85	5.90
5	+7.5	36.2	91.2									201.1	299.9	2.15	3.21		444.1	542.9	4.75	5.81
5	+15	38.1	84.8									196.6	295.4	2.10	3.16		439.6	538.4	4.70	5.76
10	-5	38.3	93.5									205.5	304.3	2.20	3.26		448.5	547.3	4.80	5.85
10	0	38.2	105.0									216.9	315.7	2.32	3.38		459.9	558.7	4.92	5.98
10	+7.5	34.1	93.3									201.1	299.9	2.15	3.21		448.1	542.9	4.75	5.81
10	+15	36.2	96.7									206.6	305.4	2.21	3.27		449.6	548.4	4.81	5.87
15	-5	38.1	98.8									210.6	309.4	2.25	3.31		453.6	552.4	4.85	5.91
15	0	37.7	105.0									216.4	315.2	2.31	3.37		459.4	558.2	4.91	5.97
15	+7.5	32.7	88.4									194.8	293.6	2.08	3.14		437.3	536.6	4.68	5.74
15	+15	35.5	105.0	0.80.0	2.0/20.8	47.7		14.0		10.0		214.2	313.0	2.29	3.35	243.0	457.2	556.0	4.89	5.95

TABLE 28. WEIGHT TREND TABLE FOR HELICOPTER CRASH IMPACT AT 42 FPS WITH UNCOUPLED LANDING GEAR IN THE EXTENDED POSITION

Impact Attitude, Degrees		Incremental Weight Changes, Pound										Sub-Total of Incremental Weight Changes, Pound		Sub-Total Increment as Percent of Baseline		Constant Add'l Weight For All Cases, Pound	Total Weight Increase, Pound		Total Increase As Percent Of Baseline	
		Two Crew Seats	Fuse-lage	Main Landing Gear				Tail Gear												
				Cross Tube	Two Trailing Arms	Two Shock Struts		Trailing Arm		Shock Strut										
Roll	Pitch					Retr'd	Fixed	Retr'd	Fixed	Retr'd	Fixed	Retr'd	Fixed	Retr'd	Fixed		Retr'd	Fixed	Retr'd	Fixed
0	-5																			
0	0	36.2	103.2	0	7.8	63	42.0	14	21	10	2	234.2	212.2	2.50	2.27	243.0	477.2	455.2	5.11	4.87
0	+7.5																			
0	+15																			
5	-5																			
5	0	38.3	136.4	1.4	7.8	63	42.4	14	21	10	2	270.9	249.3	2.89	2.66	243.0	513.9	492.3	5.49	5.26
5	+7.5																			
5	+15																			
10	-5																			
10	0	42.0	160.2	13.8	7.8	63	44.8	14	21	10	2	310.8	291.6	3.31	3.11	243.0	553.8	534.6	5.91	5.71
10	+7.5																			
10	+15																			
15	-5																			
15	0	42.0	178.4	21.0	7.8	63	46.0	14	21	10	2	336.2	318.2	3.58	3.40	243.0	579.2	561.2	6.18	5.99
15	7.5																			
15	+15																			

NOTE: The cross-tube is made of 300M alloy steel.

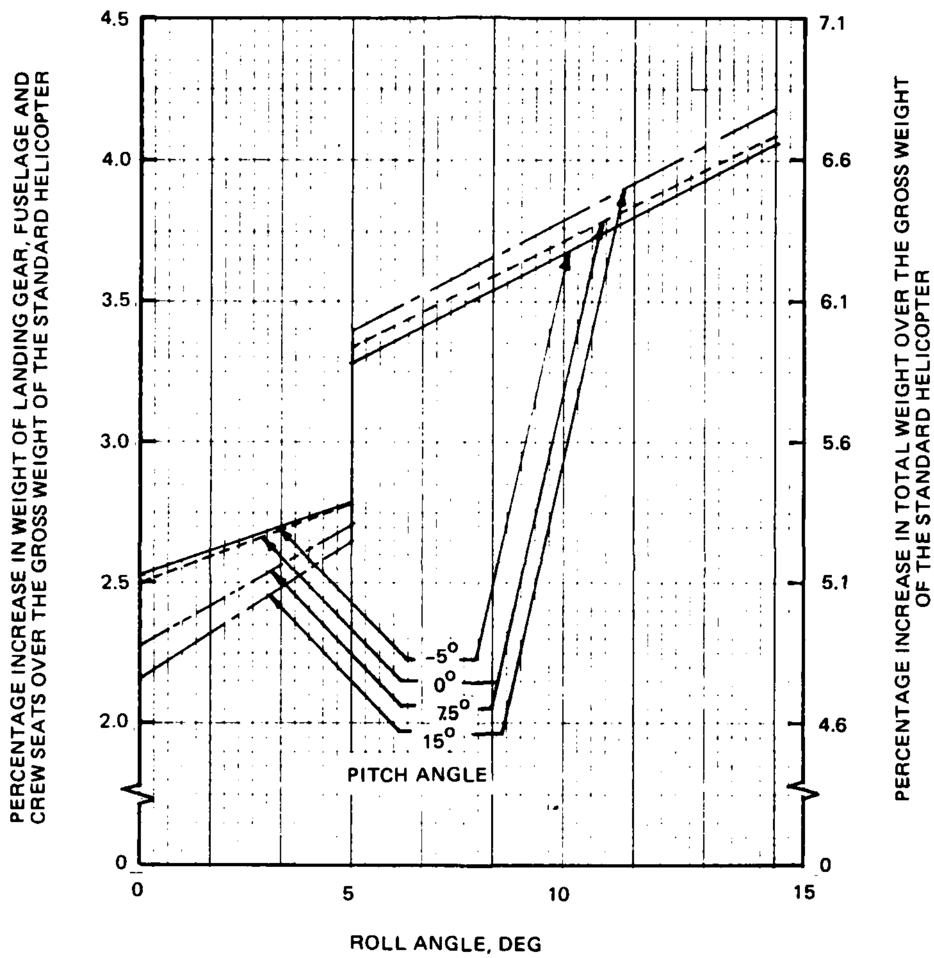

Figure 67. Percentage increase in helicopter weight with coupled crashworthy retractable landing gear in the extended position for a 42 fps impact.

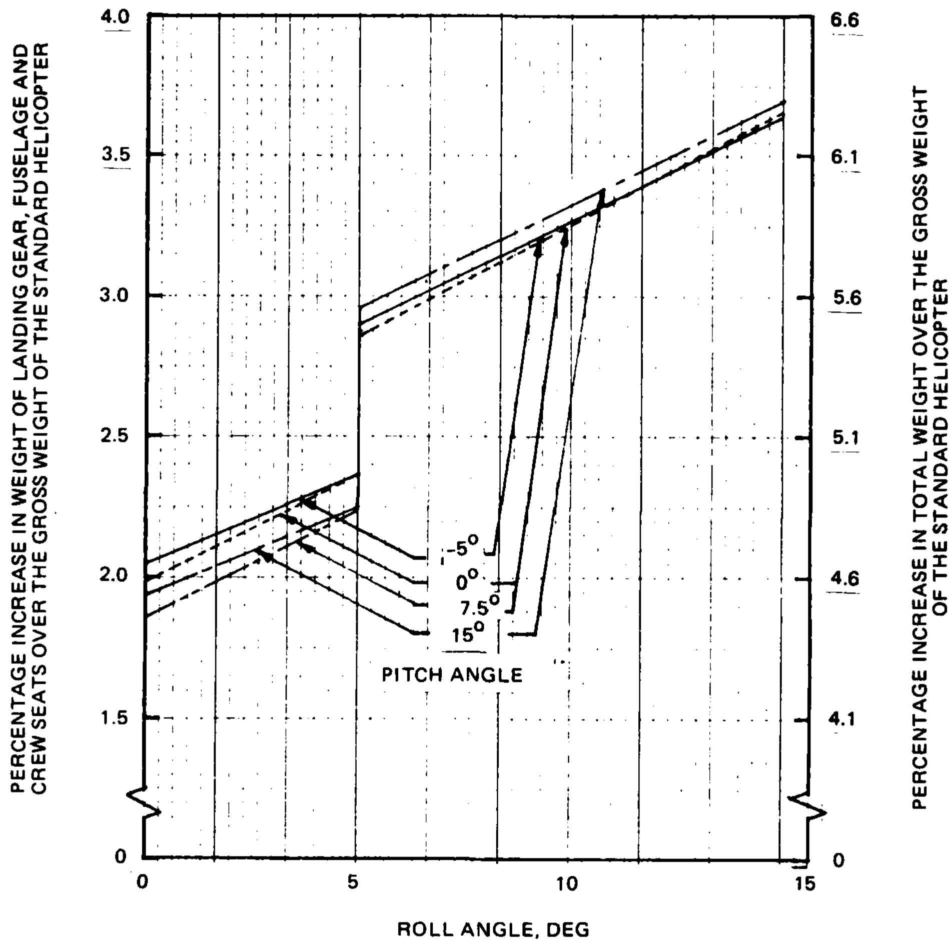

Figure 68. Percentage increase in helicopter weight with coupled crashworthy retractable landing gear in the extended position for a 36 fps impact.

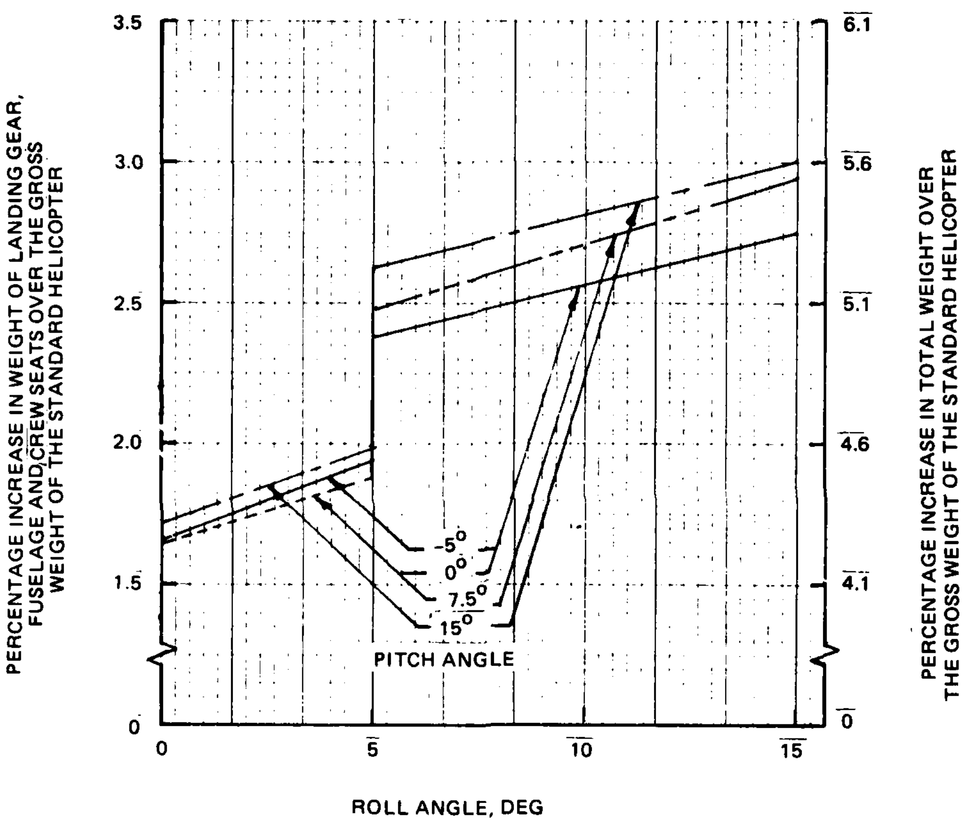

Figure 69. Percentage increase in helicopter weight with coupled crashworthy retractable landing gear in the extended position for a 30 fps impact.

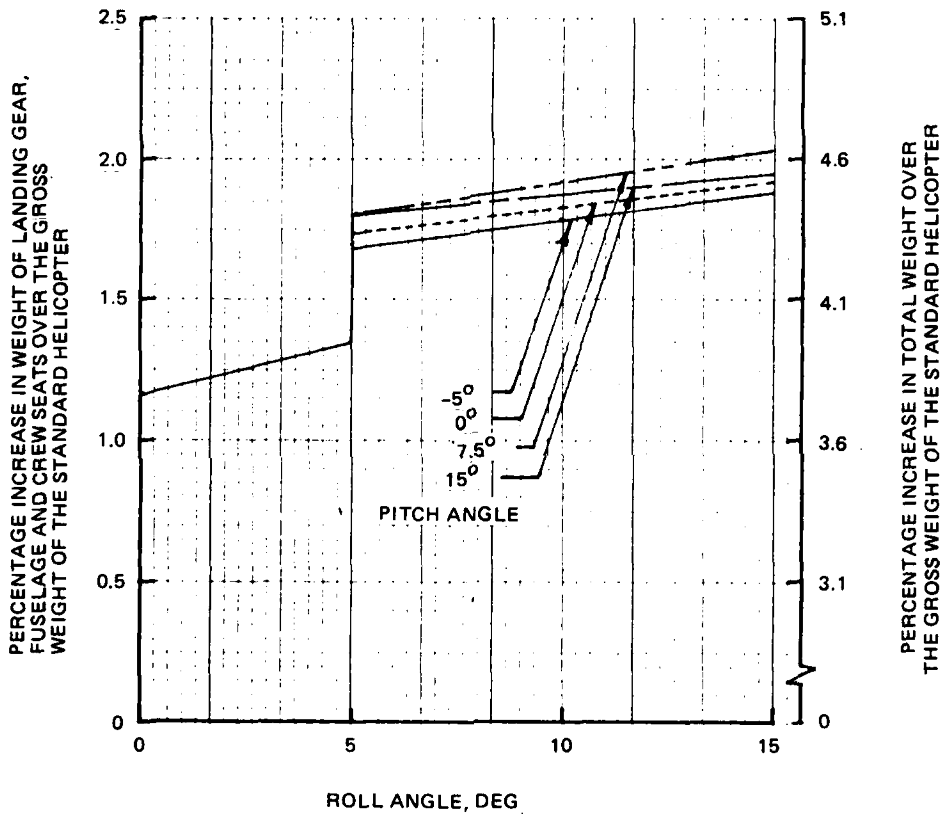

Figure 70. Percentage increase in helicopter weight with coupled crashworthy retractable landing gear in the extended position for a 20 fps impact.

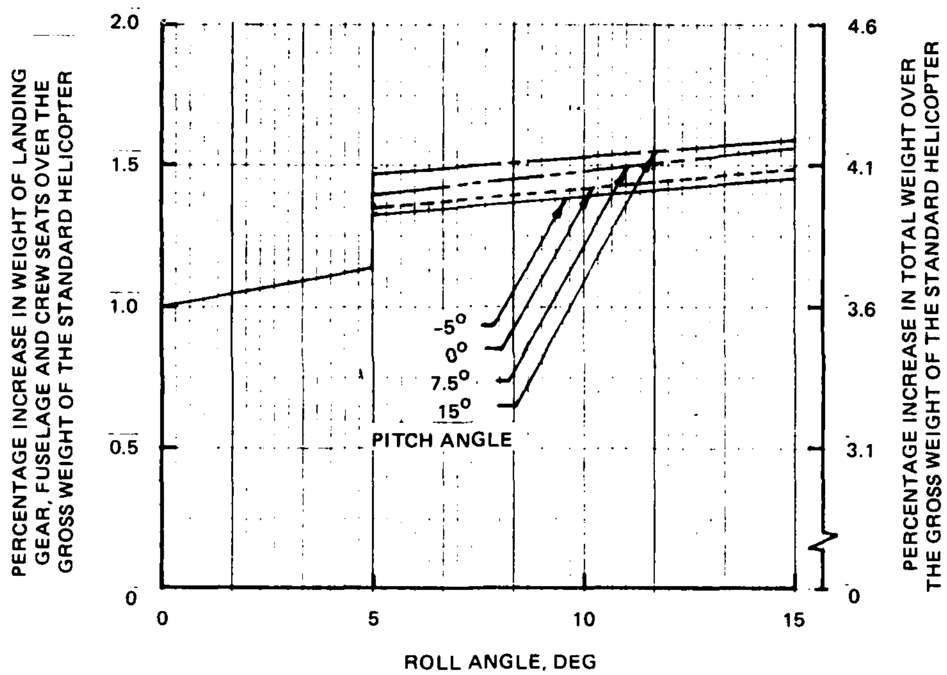

Figure 71. Percentage increase in helicopter weight with coupled crashworthy retractable landing gear in the extended position for a 15 fps impact.

influence of pitch angle at roll angles less than 5 degrees decreases with decreasing impact velocity. But at high roll angles, 5 to 15 degrees, impact at +15 degree pitch results in the highest percentage increase in weight for all impact velocities. The maximum percentage increases in weight for each of the five impact velocities are compared in Figure 72. The rate of weight increase with roll angle decreases with decreasing impact velocity. As a further comparison, the influence of roll angle is plotted in Figure 73. Over the range of sink speeds investigated, the weight increases linearly and at an increasing rate with increasing roll angle.

6.5.2 Coupled Fixed Landing Gear

The percentage increase in gross weight with respect to roll angle for five sink speeds of the coupled fixed landing gear are plotted in Figures 74 through 78. The maximum percentage increase in weight for the five impact velocities and the influence of roll angle are plotted in Figures 79 and 80, respectively. The trends in the increase in weight are similar to those for the coupled retractable landing gear. However, the gross weight of the helicopter with the coupled fixed landing gear is lighter than that of the helicopter with the coupled retractable landing gear by 0.2 to 0.4 percent of the gross weight of the standard helicopter. The difference in weight increases with decreasing impact velocity.

6.5.3 Coupled Landing Gear in Retracted Position

The percentage increases in gross weight of the fuselage with respect to the roll angle for three sink speeds are presented in Figures 81 through 83 for the coupled landing gear in the retracted position. The upper limit includes the weight of the heaviest coupled retractable landing gear, and the lower limit the lightest coupled retractable landing gear. The lower limit curves are therefore more representative of the increase in fuselage weight with the uncoupled retractable landing gear. The 0 degree pitch impact attitude is the severest on the percentage increase in weight. A comparison of the maximum (0 degree pitch) increases in weight for the three impact velocities is shown in Figure 84. The maximum available stroke of the fuselage underfloor structure is utilized for crash impacts at 35 fps. Moreover, the difference in the increase in weight for 10 and 15 degree roll impact is negligible. In a design with an uncoupled landing gear, the fuselage will not "bottom out" at 35 fps because of the additional (or, more energy-absorbing) material in the underfloor structure.

6.5.4 Uncoupled Retractable Landing Gear

The data for the percentage increase in gross weight for the helicopter with the uncoupled landing gear for an impact velocity of 42 fps at 0 degree pitch was presented in Table 28. The data are for a steel cross tube. On the basis of this data at 42 fps and the behavior of the maximum percentage increases in weight of the coupled retractable landing gear of Figure 72, the percentage increases in weight with the uncoupled landing gear were estimated for impact

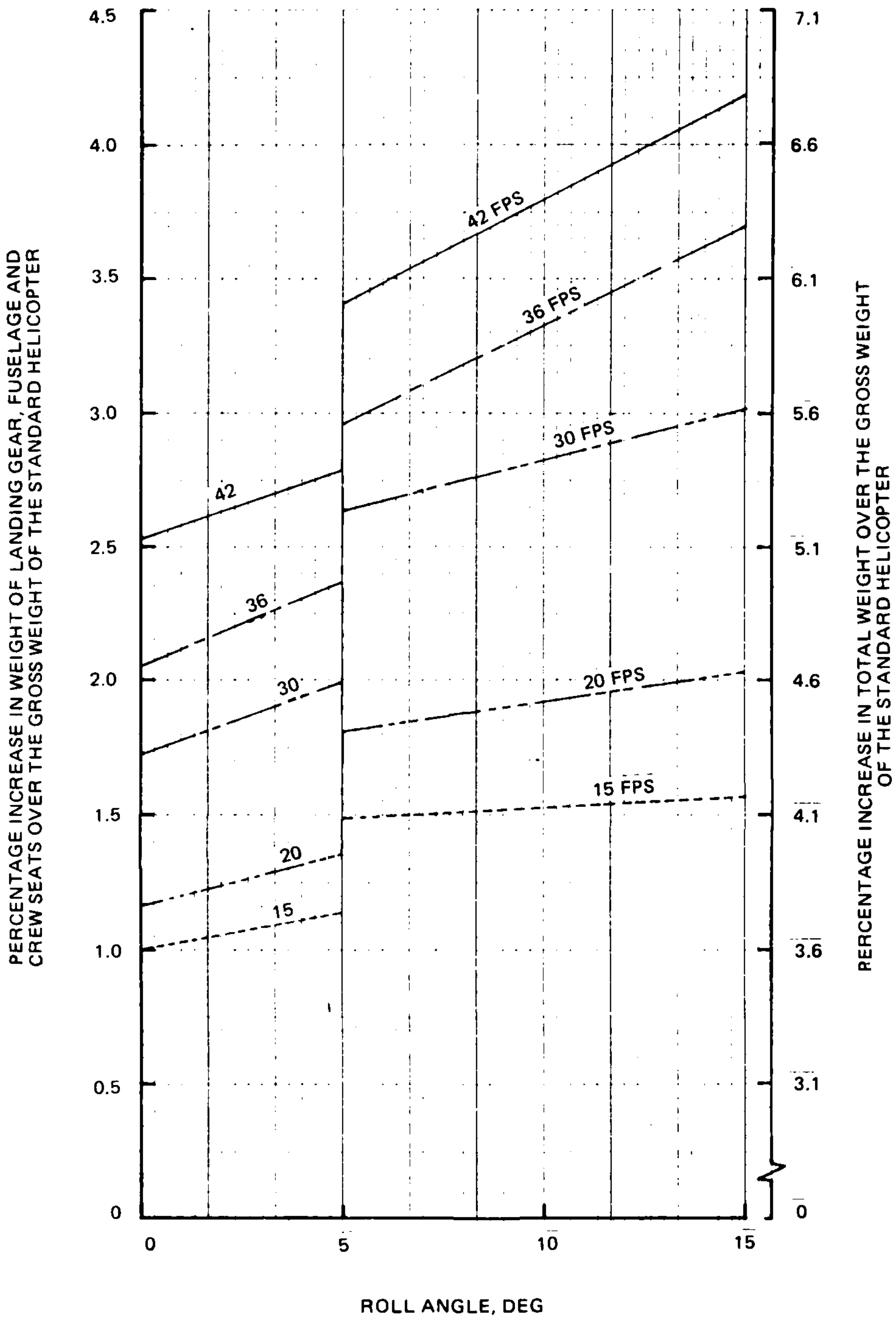

Figure 72. Maximum percentage increases in helicopter weight with coupled crashworthy retractable landing gear for five sink speeds.

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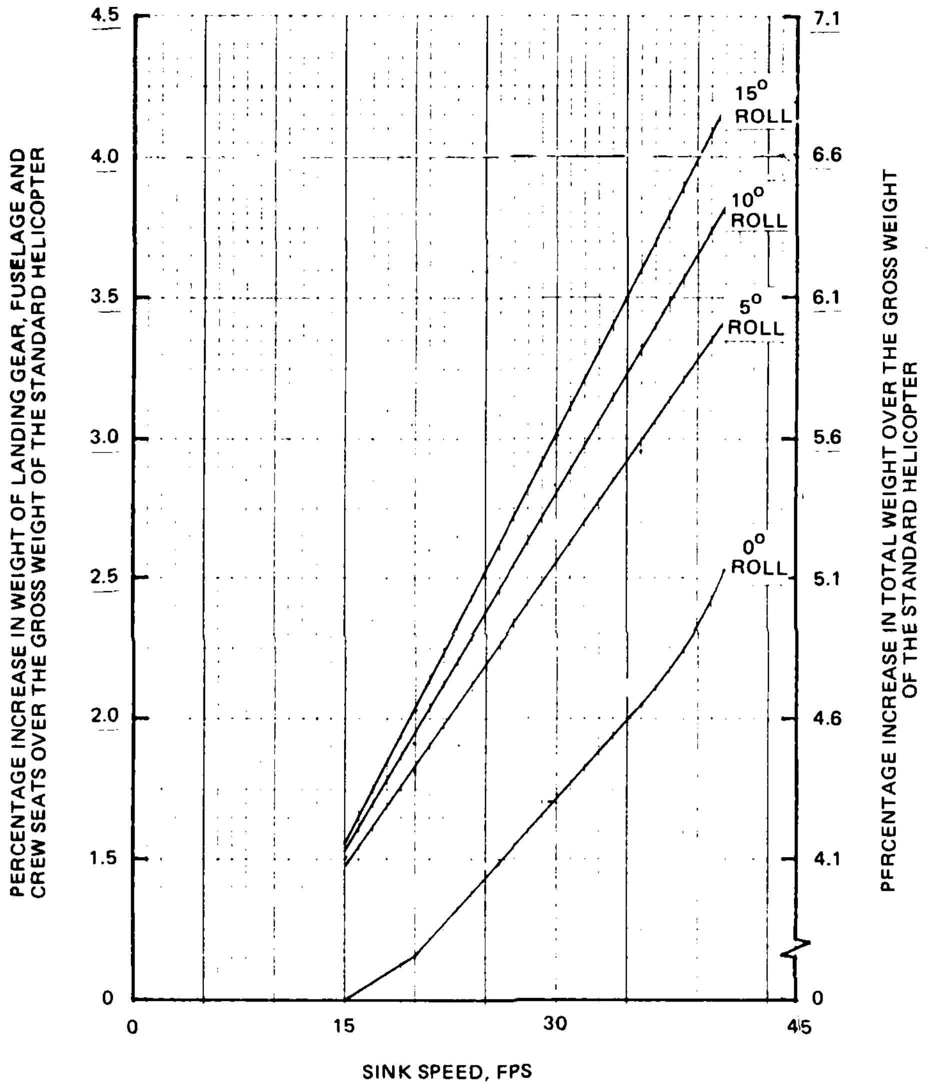

Figure 73. Maximum percentage increases in helicopter weight with coupled crashworthy retractable landing gear for four impact roll angles.

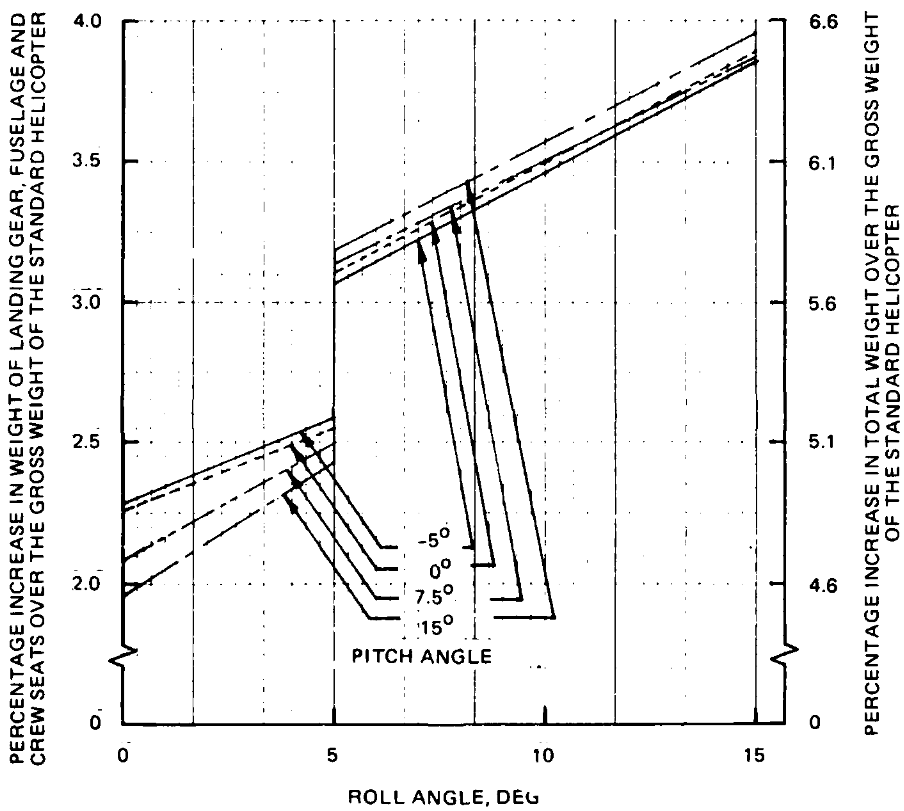

Figure 74. Percentage increase in helicopter weight with coupled crashworthy fixed landing gear for a 42 fps impact.

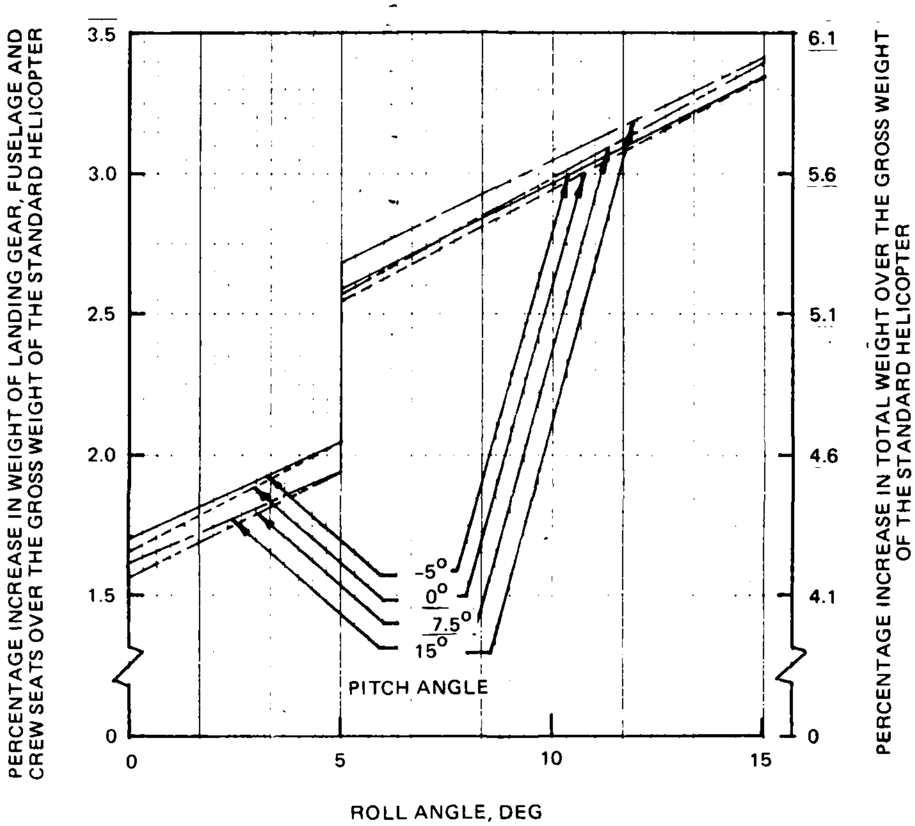

Figure 75. Percentage increase in helicopter weight with coupled crashworthy fixed landing gear for a 36 fps impact.

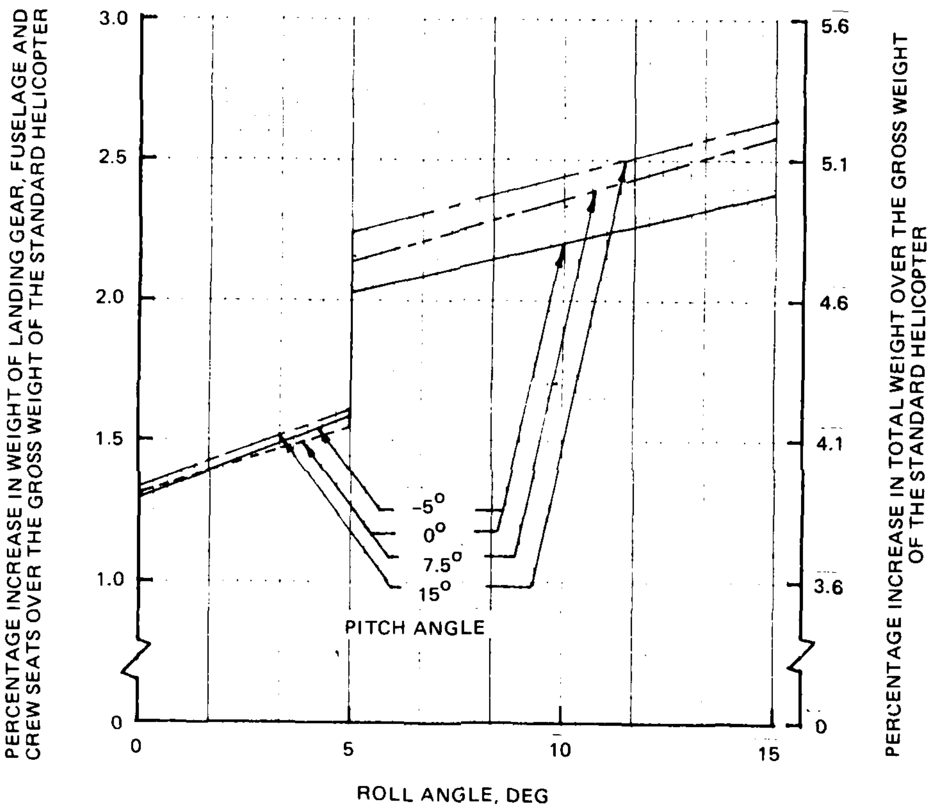

Figure 76. Percentage increase in helicopter weight with coupled crashworthy fixed landing gear for a 30 fps impact.

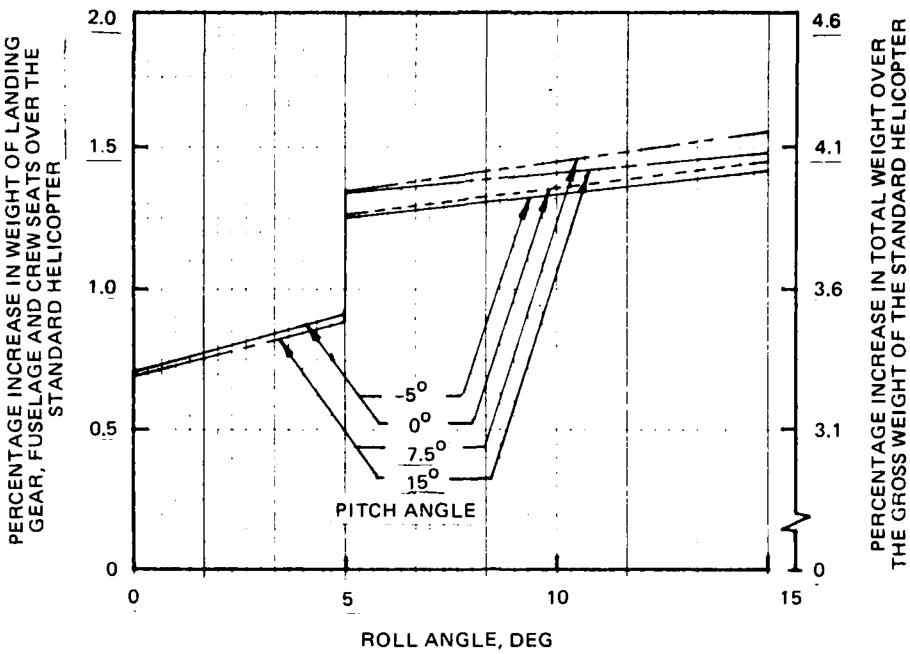

Figure 77. Percentage increase in helicopter weight with coupled crashworthy fixed landing gear for a 20 fps impact.

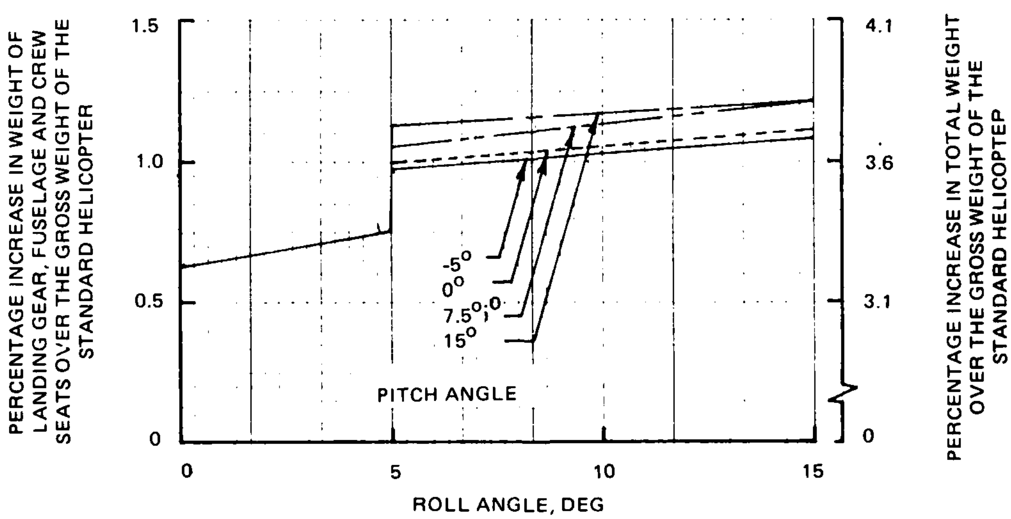

Figure 78. Percentage increase in helicopter weight with coupled crashworthy fixed landing gear for a 15 fps impact.

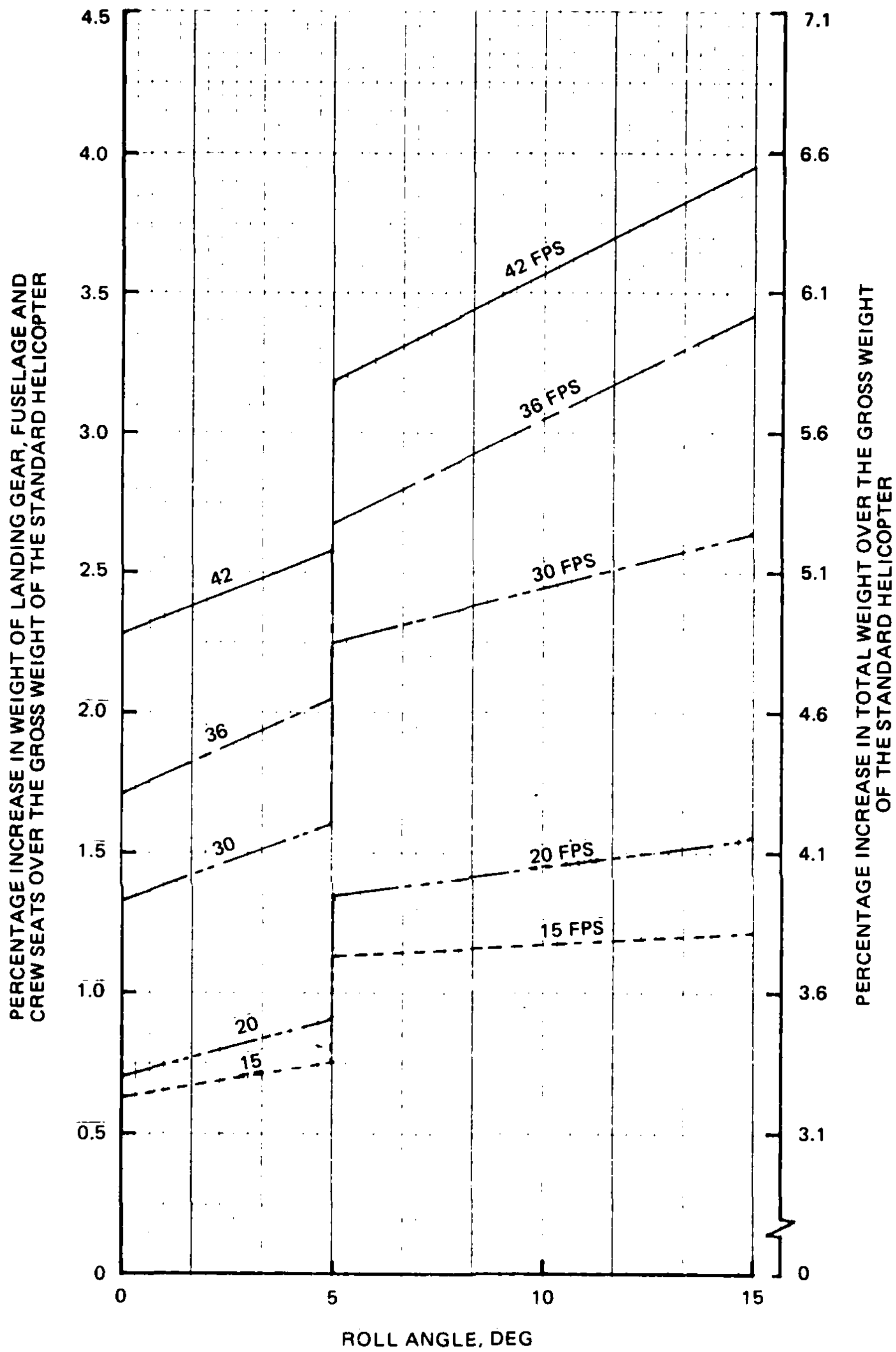

Figure 79. Maximum percentage increase in helicopter weight with coupled crashworthy fixed landing gear for five sink speeds.

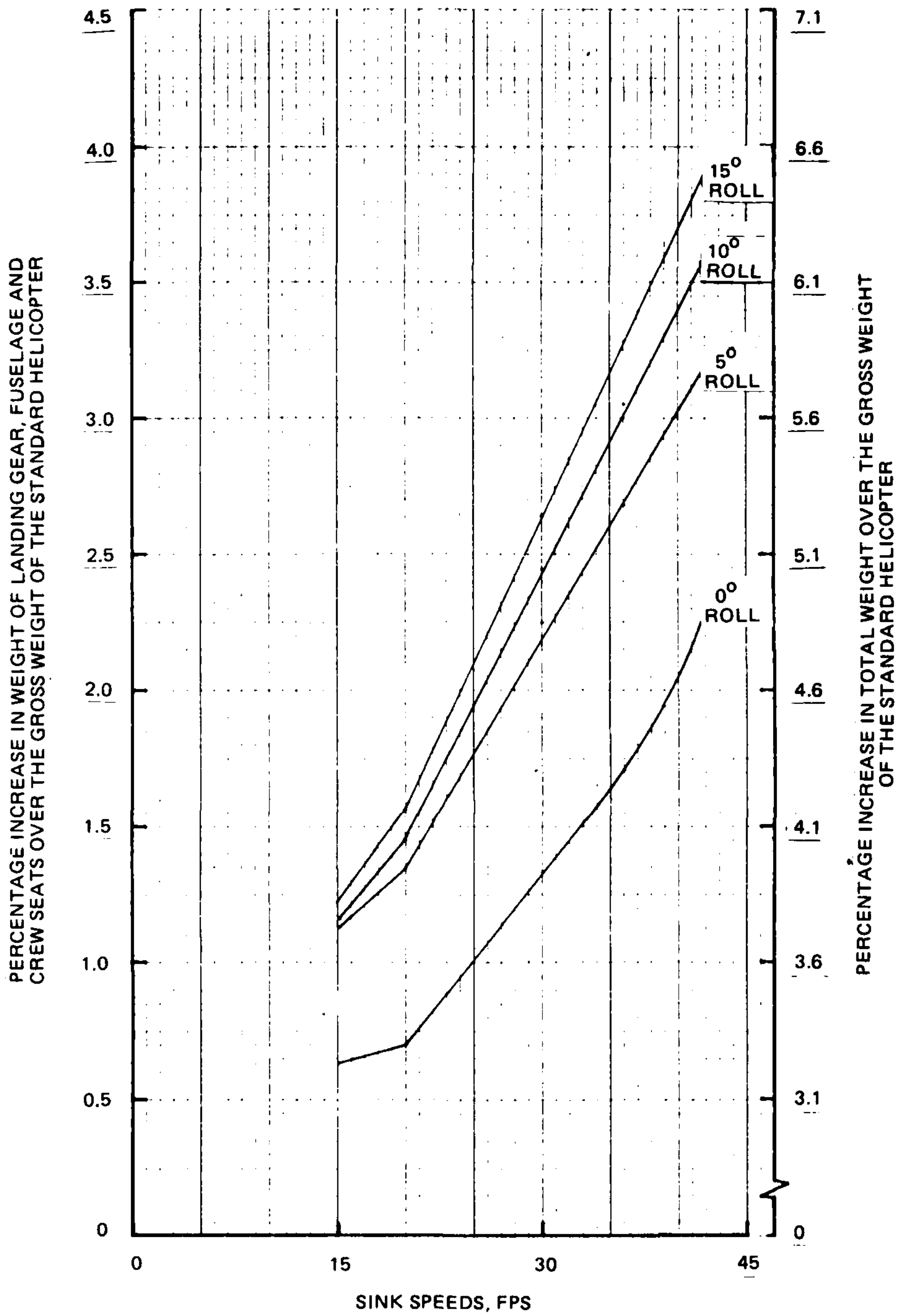

Figure 80. Maximum percentage increase in helicopter weight with coupled crashworthy fixed landing gear for four impact roll angles.

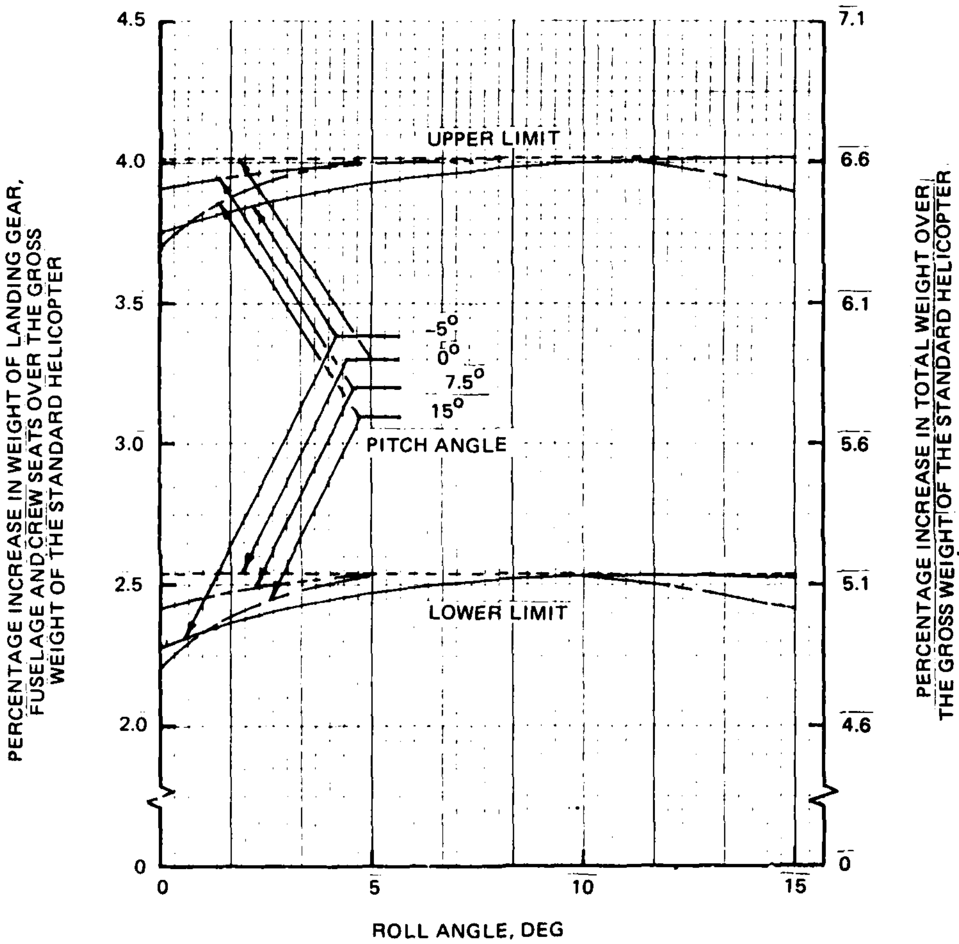

Figure 81. Upper and lower limits of percentage increase in helicopter weight with the landing gear retracted for a 35 fps impact.

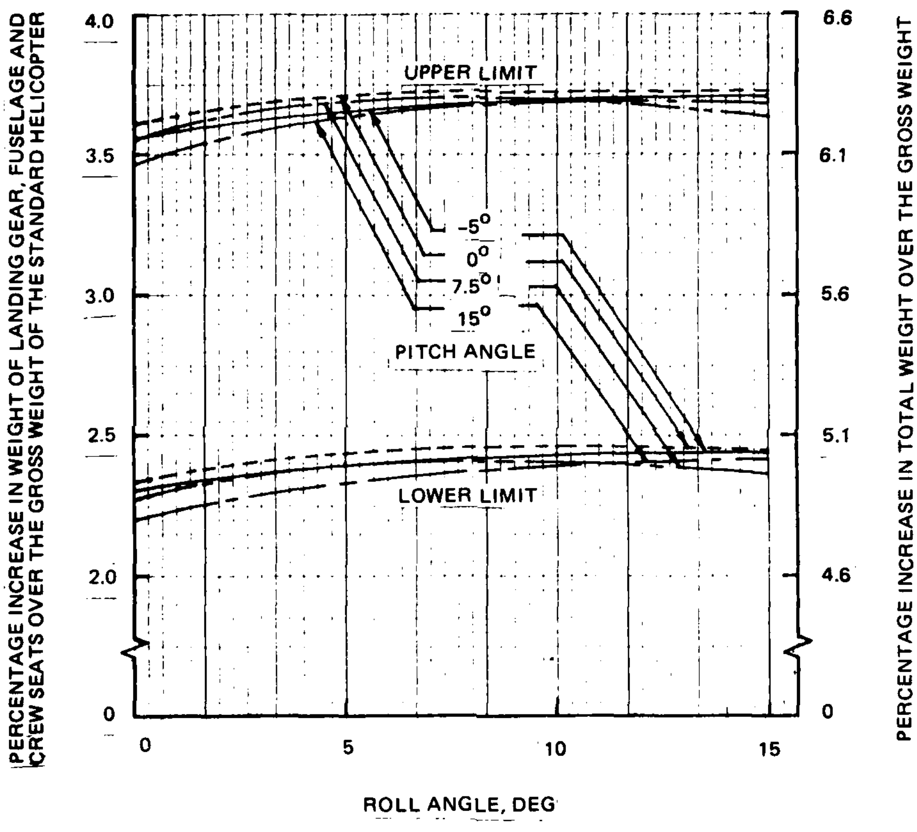

Figure 82. Upper and lower limits of percentage increase in helicopter weight with the landing gear retracted for a 30 fps impact.

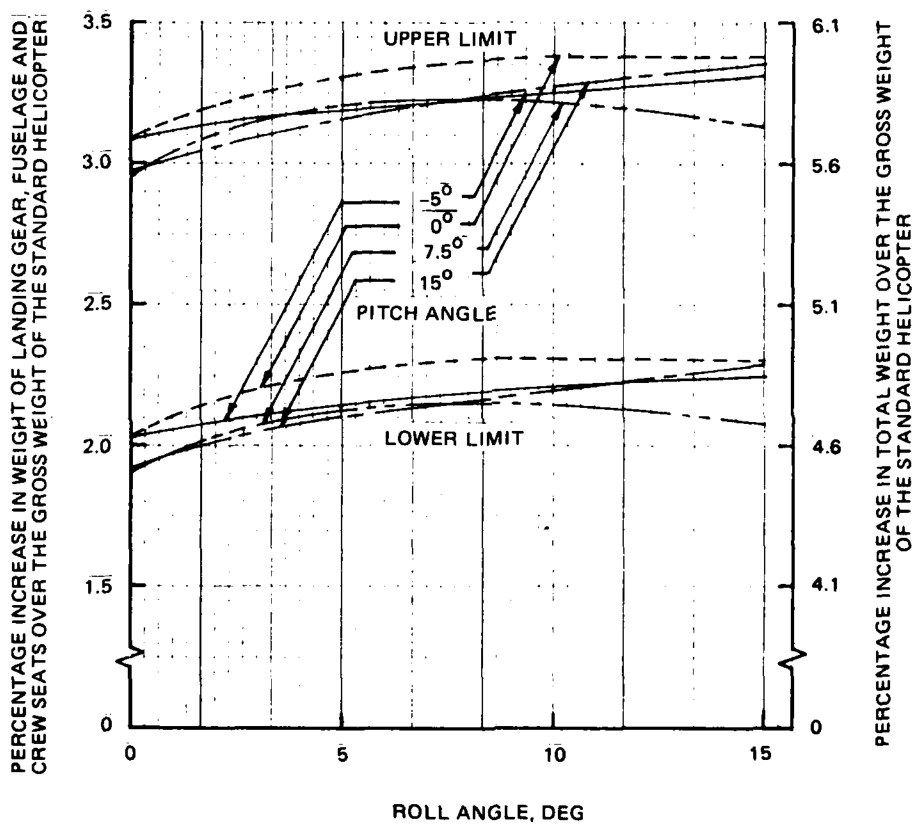

Figure 83. Upper and lower limits of percentage increase in helicopter weight with the landing gear retracted for a 25 fps impact.

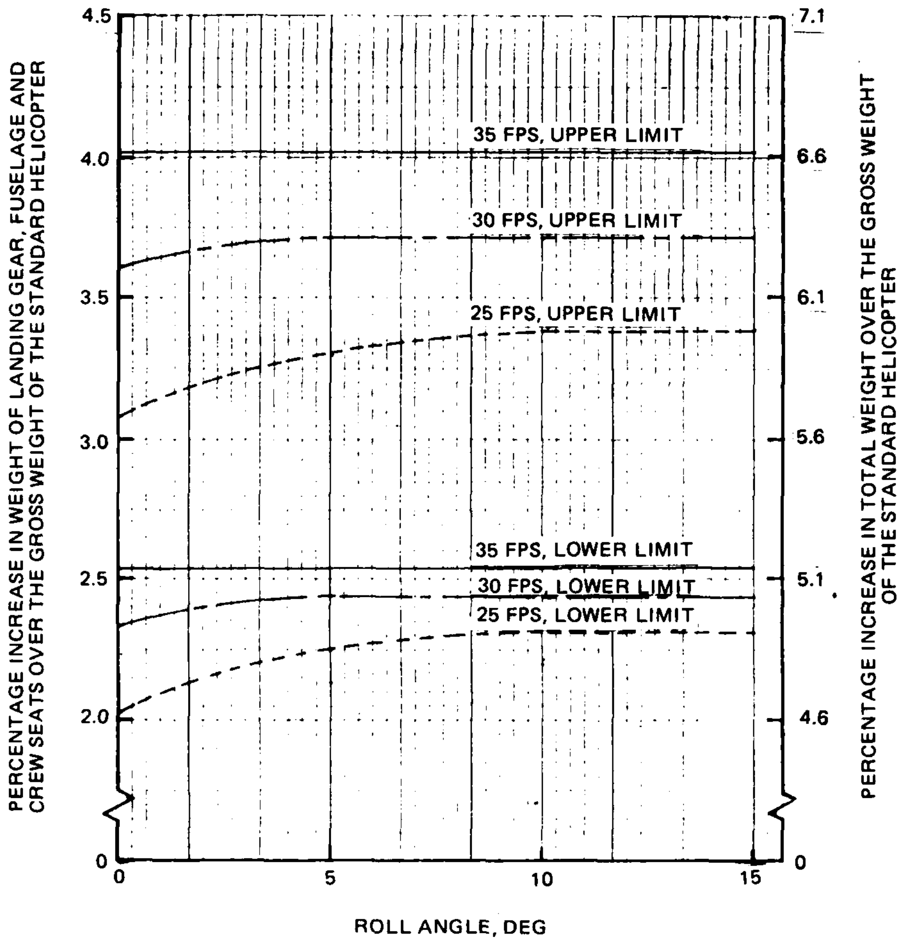

Figure 84. Maximum upper and lower limits of percentage increases in helicopter weight with the landing gear retracted for three sink speeds.

velocities of 36, 30, 20 and 15 fps. A comparison of influences of each of the five impact velocities for the case of the uncoupled retractable landing gear is presented in Figure 85 and of the uncoupled fixed landing gear in Figure 86. The weight increases with increasing impact velocity and increasing roll angle. Though the rate of increase in weight between 0- and 5-degree roll impact angle is almost constant for all impact velocities, it decreases with decreasing impact velocity for impacts between 5 and 15 degrees roll angles.

With a graphite/epoxy cross tube, the landing gear is lighter and the percentage increase in weight of the uncoupled landing gears is lower. As seen in Tables 11 and 19, the composite cross tube results in a 19 pound lighter helicopter for a 42 fps crash impact at 15 degree roll and 0 degree pitch. The comparative weight trend curves for the two designs of the cross tubes for retractable and fixed uncoupled landing gears are shown in Figure 87. The weight advantage decreases with decreasing roll angle.

6.6 DISCUSSION

The data presented for the weight sensitivity analysis completely covers the cases of uncoupled and coupled, and retractable and fixed landing gears in the extended and retracted positions. The weight trend curves of Figure 88 is a composite of the retractable coupled and uncoupled gear configurations for three sink speeds. The figure is a typical graphical illustration of the influences of the impact parameters on the weight increases for the different designs. The highlights of the influences are that the increment in helicopter weight:

- Increases with increasing impact velocity
- Increases with increasing roll angle
- Is greatest for +15 degrees pitch impact angle for all velocities for coupled landing gear design
- Is greatest for 0 degree pitch impact angle for all velocities for uncoupled landing gear design
- Decreases with increasing roll angle for crash impact with the landing gear retracted
- Increases at an increasing rate with increasing impact velocity for all landing gear designs

The helicopter design with the uncoupled landing gear is 53 pounds or 0.60 percent lighter than the design with the coupled landing gear, and the composite cross tube results in a helicopter which is an additional 19 pounds lighter for the most severe crash impact condition.

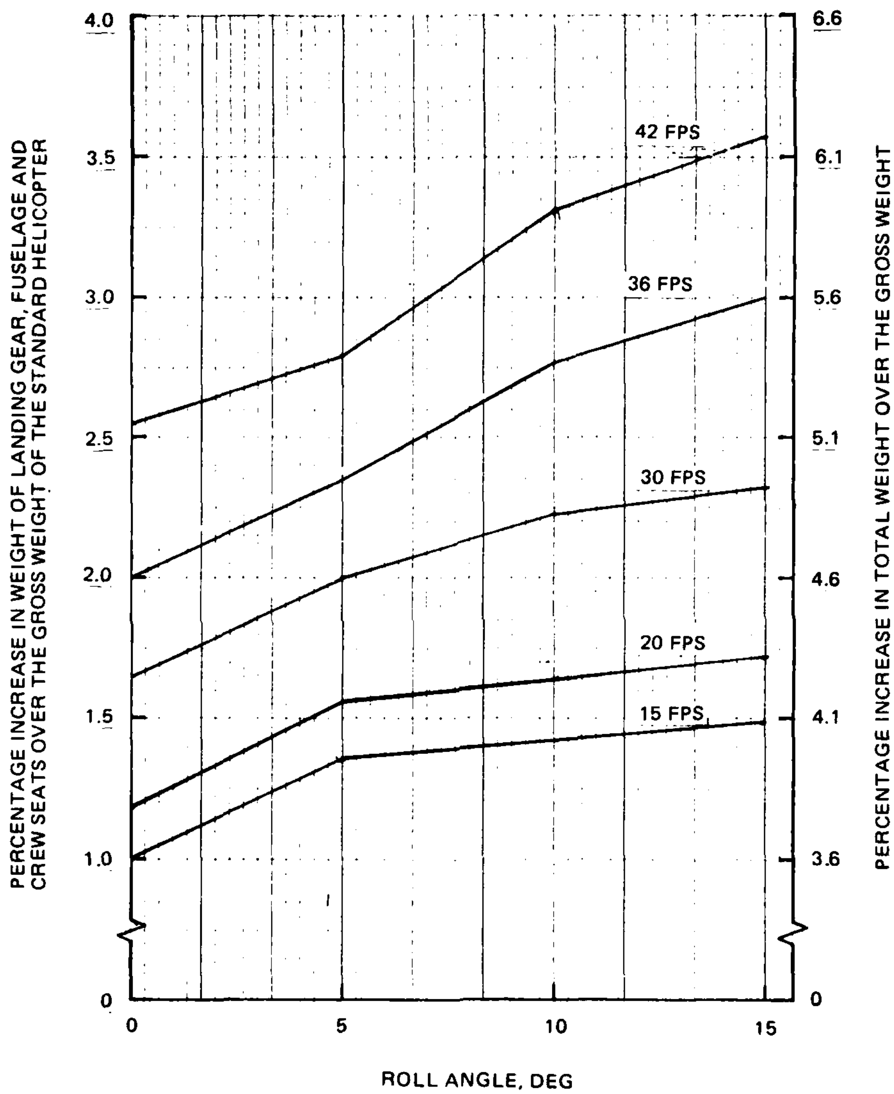

Figure 85. Comparison of the percentage increases in helicopter weights with uncoupled retractable landing gear in the extended position with impact at 0 degree pitch.

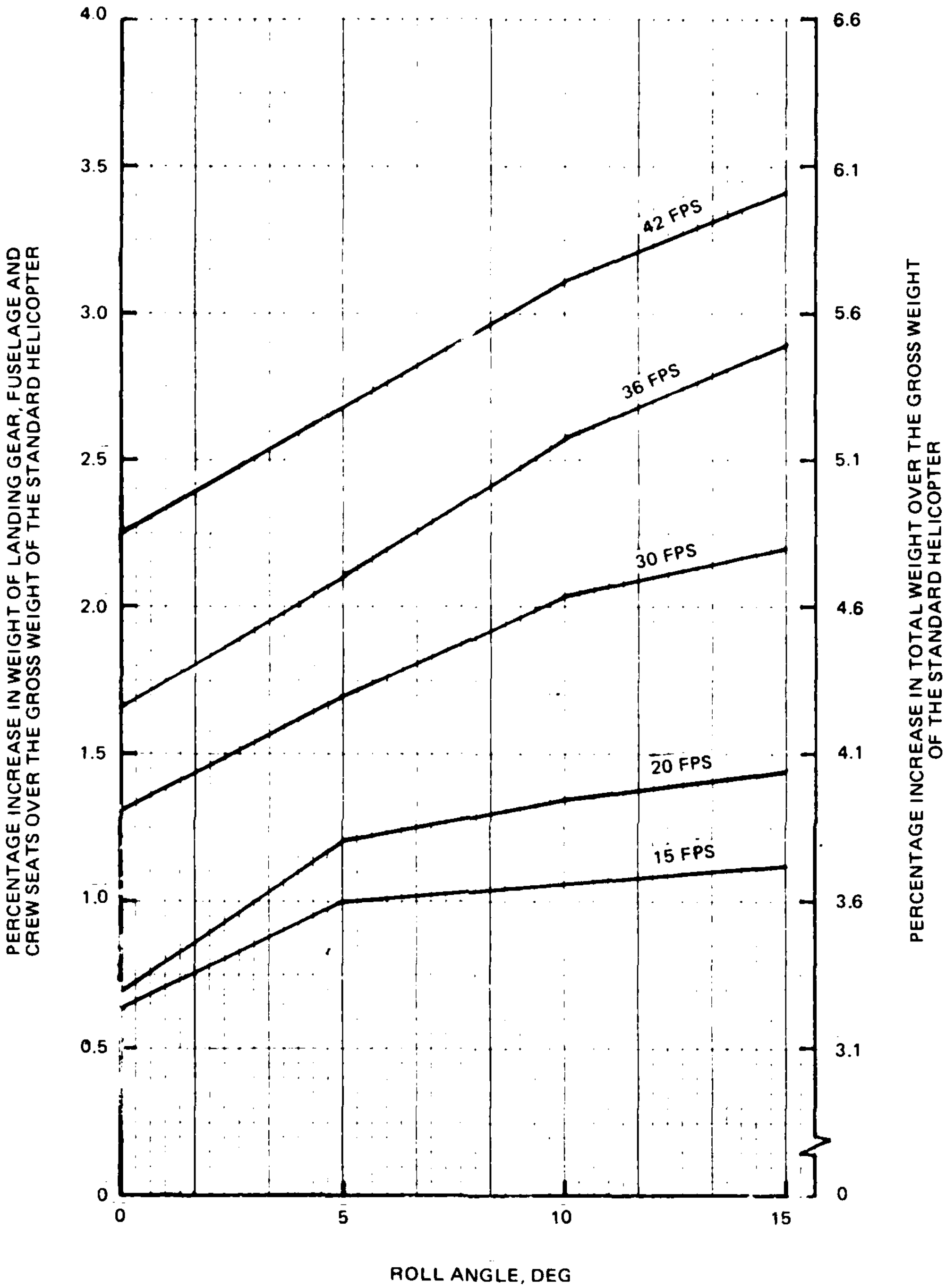

Figure 86. Comparison of the percentage increases in helicopter weights with uncoupled fixed landing gear with 300M alloy steel cross tube for an impact at 0 degree pitch.

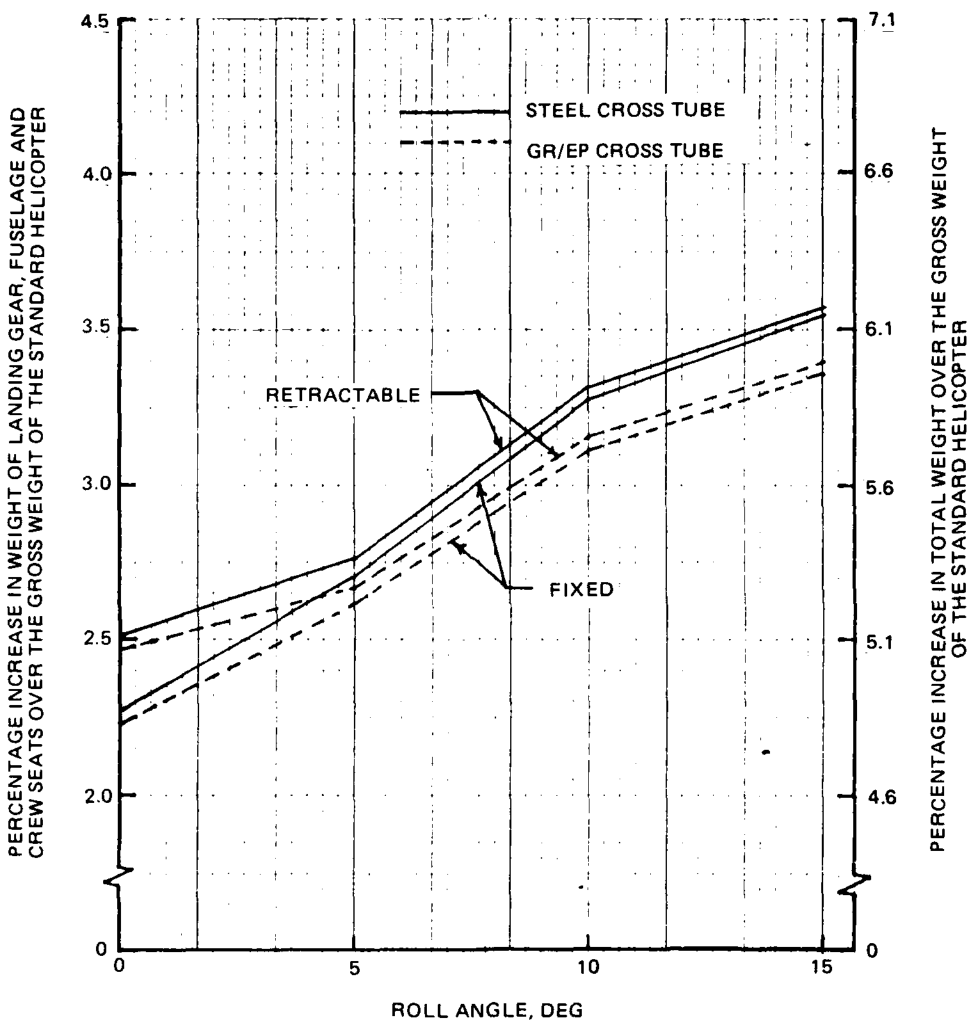

Figure 87. Comparison of percentage increase in helicopter weight for uncoupled landing gear with steel and graphite/epoxy cross tubes.

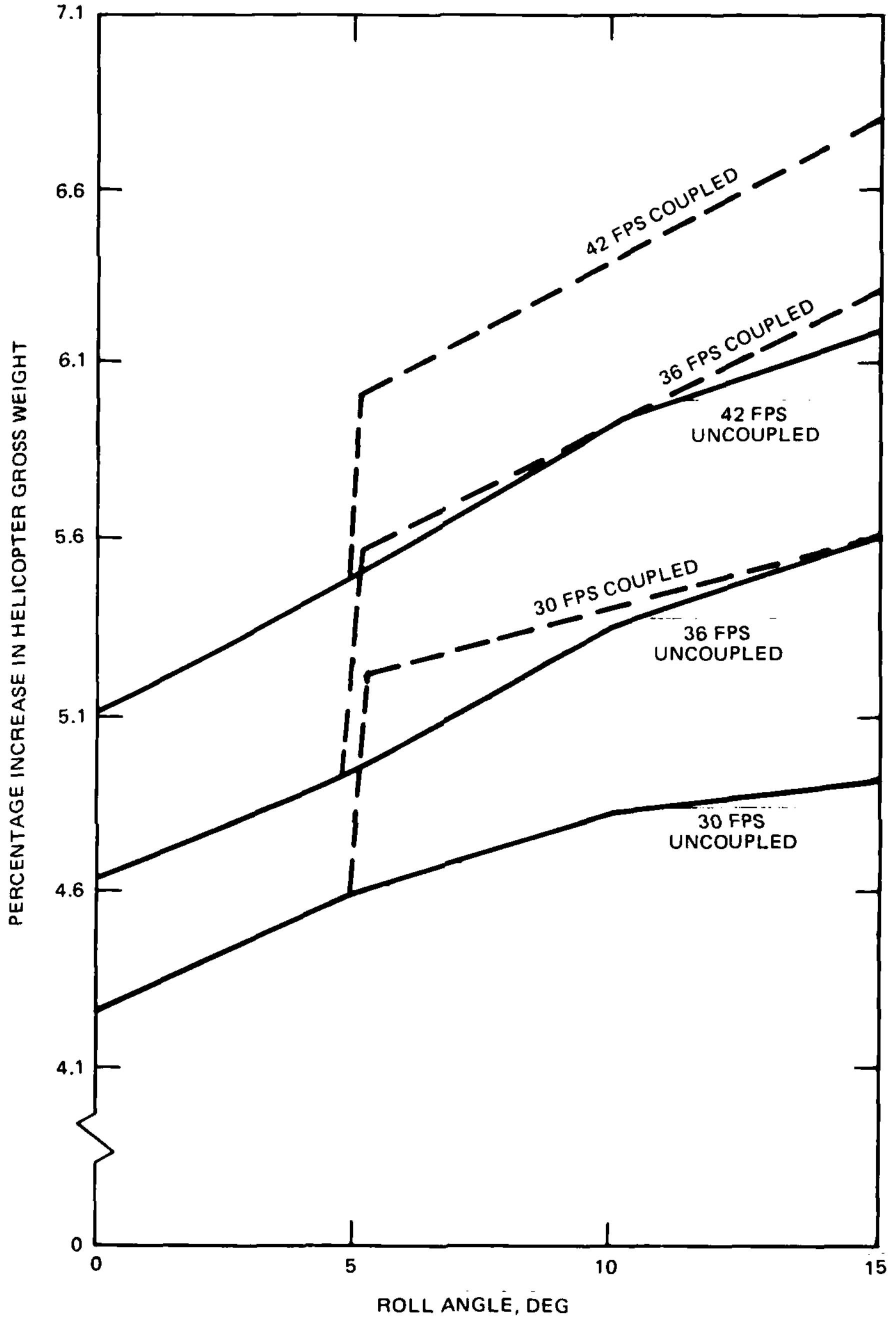

Figure 88. Comparison of weight trend curves for helicopters with coupled and uncoupled retractable landing gears.

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SECTION 7

SUMMARY OF RESULTS

7.1 THE DESIGNS

The program consisted of the preliminary designs of five landing gears and the calculation of their weights by evaluating their crashworthiness using program KRASH. The five landing gears studied were

- Standard (noncrashworthy) landing gear
- Retractable and fixed crashworthy landing gears with coupled trailing arms
- Retractable and fixed crashworthy landing gears with uncoupled trailing arms

The designs apply the systems approach to crashworthiness where the total energy is absorbed by the landing gear, fuselage and crew seat. Thus, in addition to the landing gears, two baseline helicopters were also designed: (1) a noncrashworthy fuselage for the standard landing gear and (2) a crashworthy fuselage for the four crashworthy landing gears.

The designs were completed following a preliminary KRASH investigation and an iterative process of trade-off studies between weight, drag, ground resonance, material and cost. The coupled crashworthy landing gears, which provided good resistance to crash in high roll impact attitudes, were designed using conventional 300M alloy steel material. For the uncoupled crashworthy landing gears, which are lighter than the coupled gears, conventional materials were used for all components except the graphite/epoxy cross tube. The crashworthy fuselage was designed using composite materials.

7.2 CRASHWORTHINESS REQUIREMENTS AND COMPONENT SIZING

Crashworthiness of the designs was evaluated for symmetrical (0 degree roll) and nonsymmetrical crash impact. Preliminary requirements were first investigated with KRASH for sink speeds ranging between 20 and 42 fps, roll angles between 0 and 20 degrees, and pitch angles between -10 and +20 degrees. Following detail designs of the landing gears, extensive KRASH analyses were completed with the landing gears extended for five sink speeds of 42, 36, 30, 25 and 15 fps, and with the gears retracted for three sink speeds of 35, 30, and 25 fps. For each sink speed, sixteen attitude conditions of four roll angles (0, 5, 10 and 15 degrees) and four pitch angles (-5, 0, +7.5, and +15 degrees) were investigated.

The results from KRASH analyses and static structural analyses were then used to size the landing gear, fuselage and crew seat according to the loads and deformations necessary to absorb the energy for the given crash-impact condition. The weights of the crashworthy components, and consequently the increments in weights above the standard design, were calculated from their sizes. This was done for each of 163 cases.

7.3 RESULTS OF KRASH ANALYSES

The results of KRASH analyses are summarized below and presented as Phase I and II activities.

7.3.1 Phase I Results

The 26 crash impact conditions investigated in this phase of the program were survivable. The results from this phase are summarized below.

- The maximum strokes/deformations, together with the respective impact condition, for each crashworthy component are given in Table 29. The impact condition for maximum stroke for each component is different, and the maximum deformation of the fuselage depends on a combination of impact parameters.

- By coupling the trailing arms of the main landing gear with a torque tube, more energy is absorbed by the landing gear with reduced maximum stroke than when the trailing arms are uncoupled. Consequently, the fuselage is required to absorb less energy and the seat stroke is less. For example, for a 42-fps, 20-degree roll impact condition, coupling the trailing arm reduces the maximum stroke of the main landing by 40 percent for +15 degree pitch (Figure 32), and the occupant seat stroke by 74 percent for 0 degree pitch (Figure 44).

- By designing fairings, into which the main landing gear retracts, to absorb energy under crash impact with the gears retracted, the deformations in the forward and mid regions of the fuselage are reduced (Figure 34), the seat stroke is increased slightly (Figure 37), and the occupant response (DRI) is unchanged (Figure 38).

- The addition of a longitudinal velocity component of 25 fps for symmetrical impact at 42 fps and -5 degree pitch angle on a rigid surface has no effect on occupant response in the vertical direction.

7.3.2 Phase II Results

The 80 crash impact conditions investigated with the coupled landing gear extended resulted in (1) no injury to the crew, (2) minor fuselage contact at 20 fps due to "tip-over" effect, and (3) minimal effect on the dynamic

TABLE 29. MAXIMUM STROKES/DEFORMATIONS OF COMPONENTS FOR PHASE I CRASHWORTHINESS REQUIREMENTS

Crashworthy Component	Sink Speed, FPS	Roll Angle, degrees	Pitch Angle, degrees	Stroke/ Deformation, inches
Main Landing Gear	42	10	-5	20.0
Tail Landing Gear	42	5	+15	12.5
Fuselage				
- Impact Condition				
- Symmetrical	42	0	-10	9.0
- Nonsymmetrical	36	20	+10	9.0
	42	10	+10	9.0
Seat	42	0	-5	14.0

components. The 48 crash impact investigations with the landing gear retracted could possibly result in crew injuries at 35 fps. The five crash impact investigations with uncoupled landing gear extended resulted in no injury to the crew.

The maximum strokes/deformations and the respective crash impact conditions for coupled and uncoupled landing gears are given in Table 30. The condition for maximum stroke for each component of the coupled landing gear configuration is different, implying that maximum crashworthiness features of all components are not required simultaneously. The maximum strokes for all components of the uncoupled landing gear configuration, however, occur for the same impact conditi n. The trends in deformation, and therefore the energy absorption capabilities of each component, are discussed below.

In the case of the helicopter with coupled trailing arms, the strokes of the main and tail landing gears, the fuselage and seat stroke increase with increasing sink speed. However, with increasing roll angle, the main gear stroke increases though the tail gear and the seat strokes decrease. The influence of a change in pitch angle on the strokes of these elements is negligible for any given roll angle. Of the nose, mid and tail regions of the helicopter fuselage the nose region exhibits the greatest deformation in percentage of available strokes for all roll angles at sink speeds below 42 fps, and the tail region the highest deformation for 42 fps and 10 and 15 degrees of roll angle. The seat stroke at 25 fps with the gear retracted is the same as that at 42 fps with the gear extended.

TABLE 30. MAXIMUM STROKES/DEFORMATIONS OF COMPONENTS FOR PHASE II CRASHWORTHINESS REQUIREMENTS

Crashworthy Component	Landing Gear	Sink Speed, FPS	Roll Angle, degrees	Pitch Angle, degrees	Stroke/ Deformation, inches
Main Landing Gear	Coupled	42	15	0	20.7
	Uncoupled	42	15	0	23.7
Tail Landiing Gear	Coupled	42	5	+15	11.7
	Uncoupled	42	5	0	8.9
Fuselage (Symmetrical Impact)	Coupled	42	0	-5	7.2
	Uncoupled	42	0	-5	7.2
Fuselage (Nonsymmetrical Impact)	Coupled	42	15	+7.5	9.3
	Uncoupled**	42	15	0	12.3
Seat	Coupled	42	0	+15	7.6
	Uncoupled	42	10	-5	11.9

*The fuselage underfloor has a maximum depth of 9 inches. The 12.3 inches of fuselage deformation for the uncoupled landing gear configuration are, therefore, academic and for the purpose of comparison only.

In the case of the helicopter with uncoupled trailing arms, the influence of the sink speed, roll angle and pitch angle exhibit the same trends as for the coupled arm configuration though the strokes are longer for the same impact condition. The maximum main landing gear stroke is 14.5 percent longer, fuselage stroke 50 percent and the seat stroke 32 percent. The most severe impact condition for the coupled arm configuration is 42 fps, 15 degrees roll and +15 degrees pitch whereas for the uncoupled arm configuration it is 42 fps, 15 degrees roll and 0 degree pitch.

7.4 WEIGHTS OF LANDING GEARS AND HELICOPTERS

The weights of the landing gears and the helicopters were calculated from the deformations required of each component to absorb the crash kinetic energy. The weights are summarized below.

- Helicopters with retractable uncoupled landing gears (with graphite/epoxy cross tubes) were the lightest in design and are lighter than those with coupled landing gears by 0.77 percent for the most severe impact condition.

- Helicopters with fixed landing gears are 0.6 percent lighter than those with retractable landing gears for the most severe impact conditions.

- The weights of the crashworthy helicopters increase with sink speed, increase with roll angle, and generally increase with pitch angle for coupled landing gears.

The maximum weights of the six landing gear designs and the corresponding maximum weights of the helicopter for the five sink speeds are summarized in Tables 31 and 32, respectively. The maximum percentage increases in gross weights of the helicpters for the five sink speeds are given in Table 33.

The landing gear and helicopter weights for the most severe impact condition analyzed are shown in Table 34.

7.5 WEIGHT TREND CURVES

Helicopter weight increases with increasing roll angle for a given sink speed. The rate of weight increase is higher for higher sink speeds and higher roll angles. Whereas for the coupled landing gear configuration the highest increase in weight is generally for +15 degree pitch angle, for the uncoupled landing gear configuration 0 degree pitch results in the most severe impact condition.

The weight trend curves shown in Figures 72 and 79 for the coupled landing gear configuration are linear over the range of roll angles for a given sink speed but with a discontinuity at 5 degrees roll angle. The uncoupled landing gear configuration results in continuous and generally nonlinear weight trend curves for the same parameters (Figures 85 and 86). The nonlinear plots have been shown as linear segments of 5 degrees roll angles because intermediate roll angles have not been investigated.

TABLE 31. SUMMARY OF MAXIMUM LANDING GEAR WEIGHTS FOR FIVE SINK SPEEDS

Sink Speed, FPS	Pitch Angle, degrees	Maximum Weight, in Pounds, of					
		Crashworthy Coupled Landing Gear		Crashworthy Uncoupled Landing Gear			
				Steel Cross Tube		Graphite/Epoxy Cross Tube	
		Retractable	Fixed	Retractable	Fixed	Retractable	Fixed
42	0	(538)	(498)	414	373	395	354
42	+15	558	517	-	-	-	-
36	0	(510)	(455)	409	398	390	379
36	+15	523	467	-	-	-	-
30	0	(478)	(414)	403	390	-	-
30	+15	492	430	-	-	-	-
20	0	(418)	(346)	373	349	-	-
20	+7.5	422	351	-	-	-	-
15	0	(388)	(325)	360	324	-	-
15	+7.5	395	332	-	-	-	-

Notes:
(1) The weights are for main and tail landing gears.
(2) The roll angle for each of the weights shown is 15 degrees.
(3) The weights of the uncoupled landing gear for 36, 30, 20 and 15 fps are estimated.
(4) The weights shown in parentheses are not the maximum for that sink speed but are included for comparison only.

TABLE 32. SUMMARY OF MAXIMUM HELICOPTER WEIGHTS FOR FIVE SINK SPEEDS

Sink Speed, FPS	Pitch Angle, degrees	Maximum Helicopter Weight, in Pounds, with					
		Crashworthy Coupled Landing Gear		Crashworthy Uncoupled Landing Gear			
				Steel Cross Tube		Graphite/Epoxy Cross Tube	
		Retractable	Fixed	Retractable	Fixed	Retractable	Fixed
42	0	(9,991)	(9,944)	9,947	9,925	9,928	9,858
42	+15	10,000	9,959	-	-	-	-
36	0	(9,949)	(9,893)	9,889	9,875	9,863	9,832
36	+15	9,954	9,944	-	-	-	-
30	0	(9,864)	(9,800)	9,827	9,813	-	-
30	+15	9,889	9,827	-	-	-	-
20	0	(9,786)	(9,714)	9,768	9,744	-	-
20	+7.5	9,797	9,719	-	-	-	-
15	0	(9,749)	(9,686)	9,749	9,713	-	-
15	+7.5	9,758	9,695	-	-	-	-

Notes:
(1) The roll angle for each of the weights shown is 15 degrees.

(2) The weights shown are for the same payload and fuel given in Table 1, and for the same weights of structural reinforcement and fuel system protection given in Table 2.

(3) The weights shown in parentheses are not the maximum for that sink speed but are incuded for comparison only.

(4) The weights of the helicopter for the uncoupled landing gear for 36, 30, 20 and 15 fps sink speeds are estimated.

TABLE 33. SUMMARY OF MAXIMUM PERCENTAGE INCREASES IN THE GROSS WEIGHTS OF THE CRASHWORTHY HELICOPTER FOR FIVE SINK SPEEDS

Sink Speed, FPS	Pitch Angle, degrees	Maximum Percentage Increase in Gross Weight of Helicopter with					
		Crashworthy Coupled Landing Gear		Crashworthy Uncoupled Landing Gear			
				Steel Cross Tube		Graphite/Epoxy Cross Tube	
		Retractable	Fixed	Retractable	Fixed	Retractable	Fixed
42	0	-	-	6.18	5.99	6.01	5.90
42	+15	6.78	6.56	-	-	-	-
36	0	-	-	5.60	5.45	5.40	5.25
36	+15	6.30	6.02	-	-	-	-
30	0	-	-	4.93	4.79	-	-
30	+15	5.60	5.25	-	-	-	-
20	0	-	-	4.30	4.05	-	-
20	+7.5	4.63	4.16	-	-	-	-
15	0	-	-	4.10	3.72	-	-
15	+7.5	4.19	3.82	-	-	-	-

Notes: (1) The roll angle for each sink speed is 15 degrees.

(2) The percentage is calculated with respect to 9365 pounds, the gross weight of the helicopter with the standard landing gear.

(3) The percentage increases in weight for the uncoupled landing gear for 36, 30, 20 and 15 fps sink speeds are estimated.

TABLE 34. SUMMARY OF CRASHWORTHY LANDING GEAR AND HELICOPTER WEIGHTS FOR MOST SEVERE IMPACT CONDITION

Weights of	Standard Retractable	Crashworthy Coupled		Crashworthy Coupled	
		Retractable	Fixed	Retractable	Fixed
Landing Gear (pounds)					
- All Steel	296	558	517	-	-
- Composite and Steel	-	-	-	395	354
Helicopter (pounds)	9,365	10,000	9,951	9,928	9,859

Notes: (1) The most severe impact condition for the crashworthy

- coupled landing gear configuration is 42 fps, 15 degrees roll and +15 degrees pitch
- uncoupled landing gear configuration is 42 fps, 15 degrees roll and 0 degree pitch.

(2) The weights of the helicopters with the crashworthy uncoupled landing gears are for the respective landing gear weights shown, i.e., with a graphite/epoxy cross tube in the composite-and-steel landing gear.

SECTION 8

RECOMMENDED DESIGN CRITERIA

8.1 GENERAL

The designs of the crashworthy landing gears satisfied the requirements of the crash impact envelope and were found to be occupant survivable for all cases. Four designs were investigated with program KRASH: (1) crashworthy retractable landing gear with a torque tube to couple the two main trailing arms, (2) crashworthy fixed landing gear with a torque tube, (3) crashworthy retractable landing gear without torque tube coupling, and (4) crashworthy fixed landing gear without torque tube coupling. In all cases, detailed breakdown of the weights of all components were calculated for combinations of five sink speeds, four roll angles and four pitch angles. The design criteria are developed from further analyses based on the frequency of occurrence of survivable helicopter accidents and on the cost of replacing equipment and crew in the case of a crash impact.

To be uniform in the development of the design criteria, the designs compared are for landing gears constructed of steel. The reduction in weight from the use of composite materials is an added advantage to be gained. This weight advantage is in addition to those gained from designing to the recommended criteria.

8.2 CUMULATIVE FREQUENCY OF ACCIDENT OCCURRENCE

The cumulative frequency of occurrence of survivable accidents is the product of the cumulative frequencies of survivable crash impact for sink speed, roll angle and pitch angle. As shown in Section 7, the influence of pitch angle on the increase in gross weight of a helicopter is negligible for a given sink speed and roll angle at impact. The cumulative frequency of occurrence of survivable accidents will, therefore, be based on the cumulative frequencies of occurrences of sink speed and roll angle.

The cumulative frequency of vertical velocity at impact is shown in Figure 89. Based on the frequency of occurrence of roll angle at impact (Figure 90), the cumulative frequency of the occurrence of roll angle at impact is plotted in Figure 91. The cumulative frequency curve for $\pm\theta$ represents the case when distinction is not made between occurrences of negative and positive roll angles, which is how program KRASH is operated.

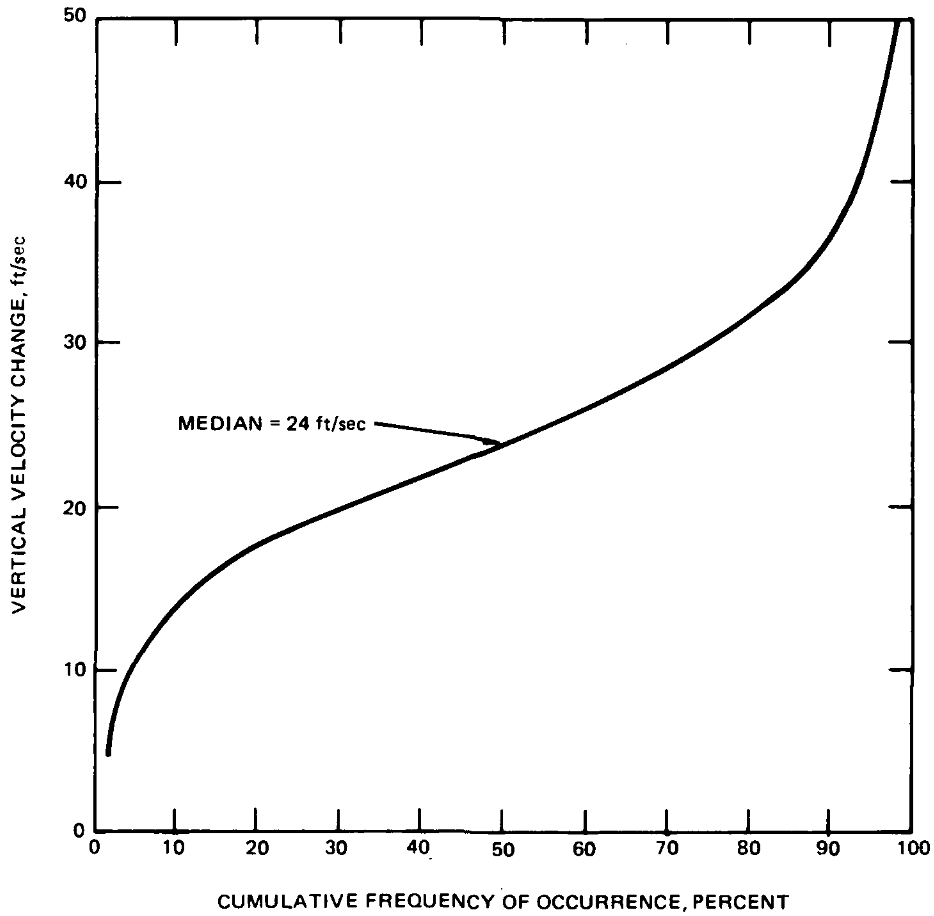

Figure 89. Cumulative frequency of occurrence of vertical velocity for survivable rotary- and light fixed-wing aircraft accidents (from Reference 6).

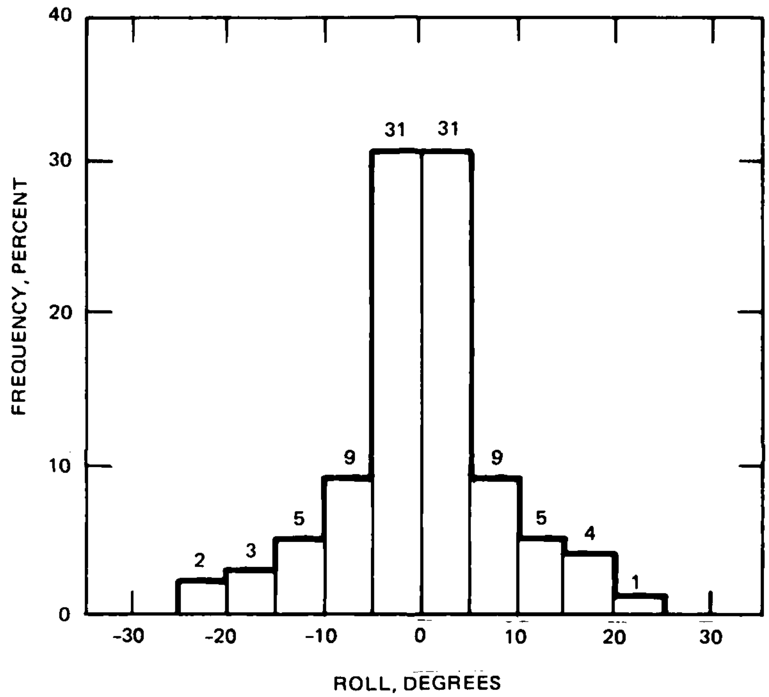

Figure 90. Frequency of occurrence of roll angle for survivable Army helicopter accidents, 1972-1982.

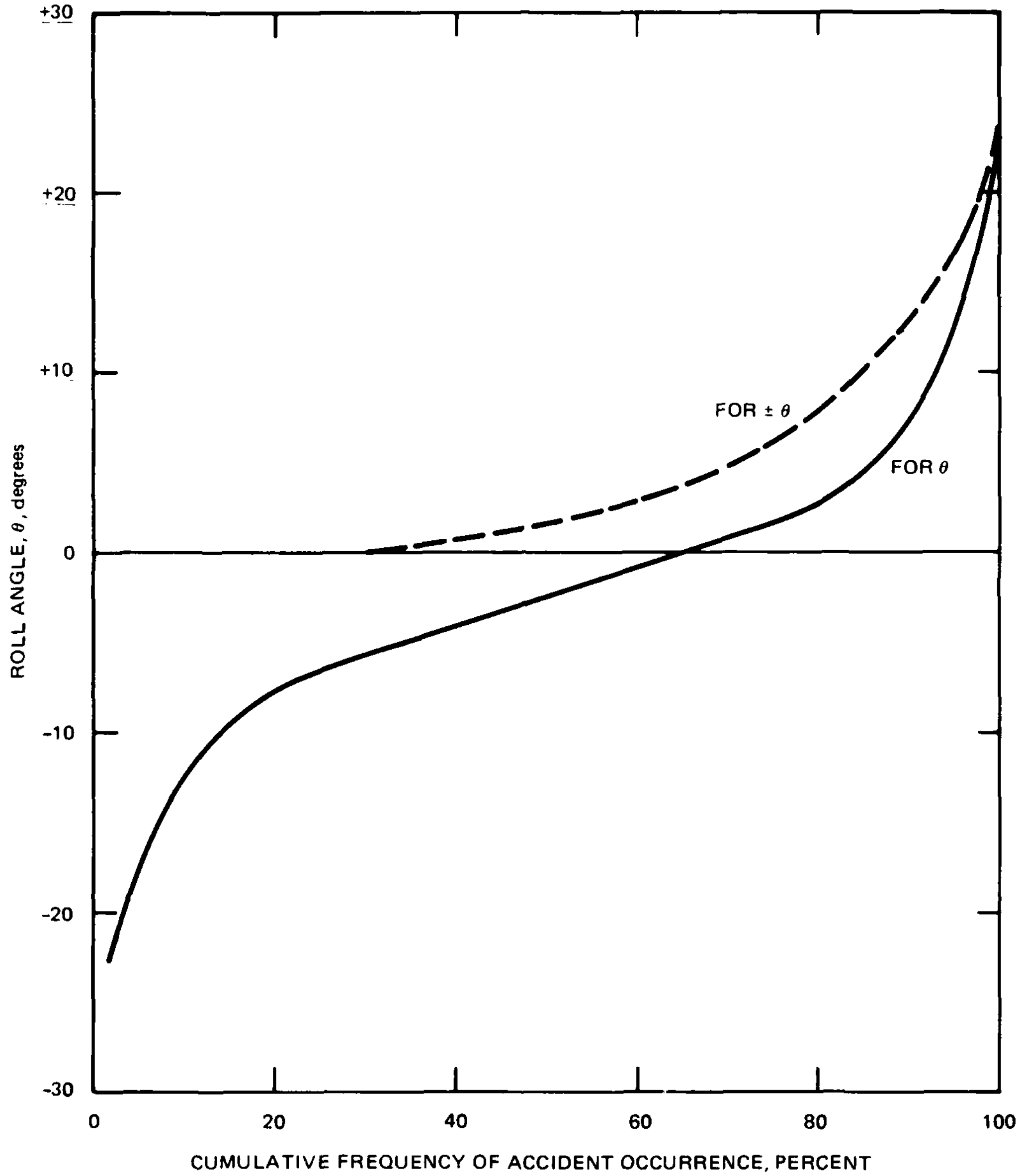

Figure 91. Cumulative frequency of occurrence of roll angle for survivable helicopter accidents, 1972-1982. (Developed from Figure 90)

The product of the cumulative frequencies of a given sink speed and a given (±) roll angle represents the cumulative frequency of occurrence of survivable helicopter accidents, which will henceforth be known as "cumulative frequency of accident occurrence." For example, the cumulative frequency of 42 fps sink speed from Figure 89 is 95 percent and the cumulative frequency of ±10 degree roll angle is 85 percent. The cumulative frequency of accident occurrence for 42 fps and ±10 degree roll angle is 95 percent x 85 percent = 80.75 percent.

Therefore, 80.75 percent of the accidents occur for conditions at or less than 42 fps sinks speed and ±10 degree roll angle. The cumulative frequency of accident occurrence is plotted in Figure 92 for sink speeds ranging between 24 and 50 fps and roll angles between 0 and ±25 degrees.

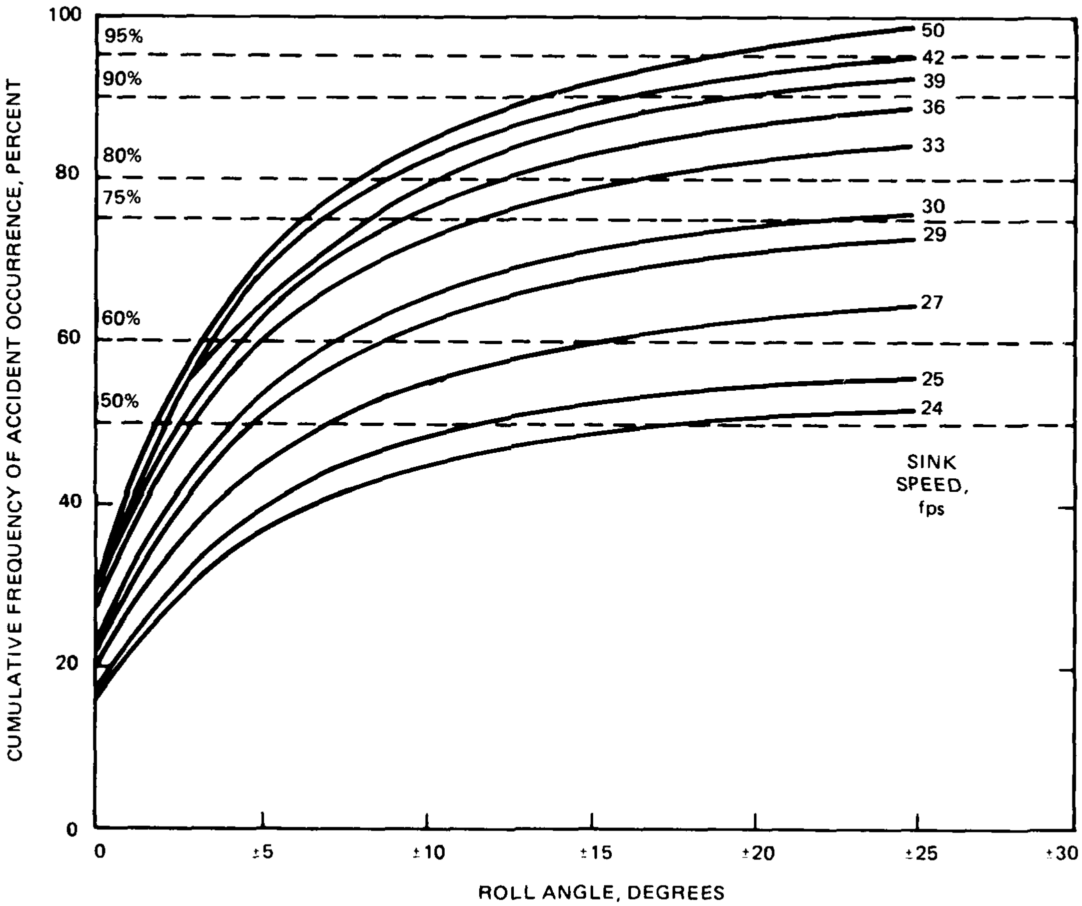

Figure 92. Cumulative frequency of occurrence of sink speed and roll angle for survivable helicopter accidents.

8.3 WEIGHT EFFECTIVE DESIGN CRITERIA

For a design to be efficient, one of the parameters to be evaluated is weight effectiveness. Weight effectiveness implies the minimum increase in weight for maximum crashworthiness. The weight is influenced by sink speed and roll angle at impact. If percentage increase in weight is plotted against sink speed and roll angle, the loci of different percentages of cumulative frequency of accident occurrence can be plotted. The 50 and 75 percent cumulative frequency curves for the percentage increase in gross weight of the helicopter with the uncoupled landing gear are shown in Figure 93. The three-dimensional plot is not practical for use as a design aid and has been reconfigured with the same parameters in Figures 94 and 95 for the coupled and uncoupled landing gears, respectively, with steel torque tube and cross tube.

The percentage increase in gross weight for the helicopter with the retractable coupled landing gear, shown in Figure 94, identifies the discontinuity in the loci of the two lower cumulative frequency curves. The discontinuities for 75 and 80 percent cumulative frequency curves occur beyond 42 fps and are not shown. The minimum weights for 50 and 60 percent cumulative frequency curves occur at 11 degrees and just under 10 degrees of roll angles for sink speeds of 25 and 28 fps, respectively. Minimum weights for the higher cumulative frequency curves do not exist.

The percentage increases in gross weights for the helicopter with retractable uncoupled landing gear for four cumulative frequency of accident occurrences are shown in Figure 95. As for the coupled landing gear configuration, minimum weights exist for the 50 and 60 percent cumulative frequency curves but none for the 75 and 80 percent curves. The minimum weights for 50 and 60 percent cumulative curves occur at 7 and 6.5 degrees for sink speeds of 27 and 30.5 fps, respectively.

The weight effective design with the coupled landing gear, therefore, has a roll angle capability 4 degrees greater than the weight effective design with the uncoupled landing gear with a marginal reduction in sink speed. The parameters of Figure 92 are replotted in Figure 96 with a different set of axes so that the loci of cumulative frequency of accident occurrences are shown together with the percentage increases in gross weight. Also plotted in Figure 96 are representative bounds and minimum thresholds of the percentage increase in gross weight, from Figures 94 and 95, for the coupled and uncoupled configurations. The bounds plotted are the loci of the combination of sink speed and roll angle resulting in 4.6 and 5.4 percent increases in gross weight for the uncoupled configuration, and 5.2 and 6.0 percent for the coupled configuration. The 5.4 percent locus for the uncoupled configuration is identical to the 6.0 percent locus for the coupled configuration. Similarly, the uncoupled 4.6 percent locus is the same as the coupled 5.2 percent locus. These bounds indicate that the coupled configuration is 0.6 percent heavier than the uncoupled configuration. Whereas the bounds provide the interrelationship between the weight increases for the two landing gear configurations and the cumulative frequency of accident occurrence, the thresholds identify the

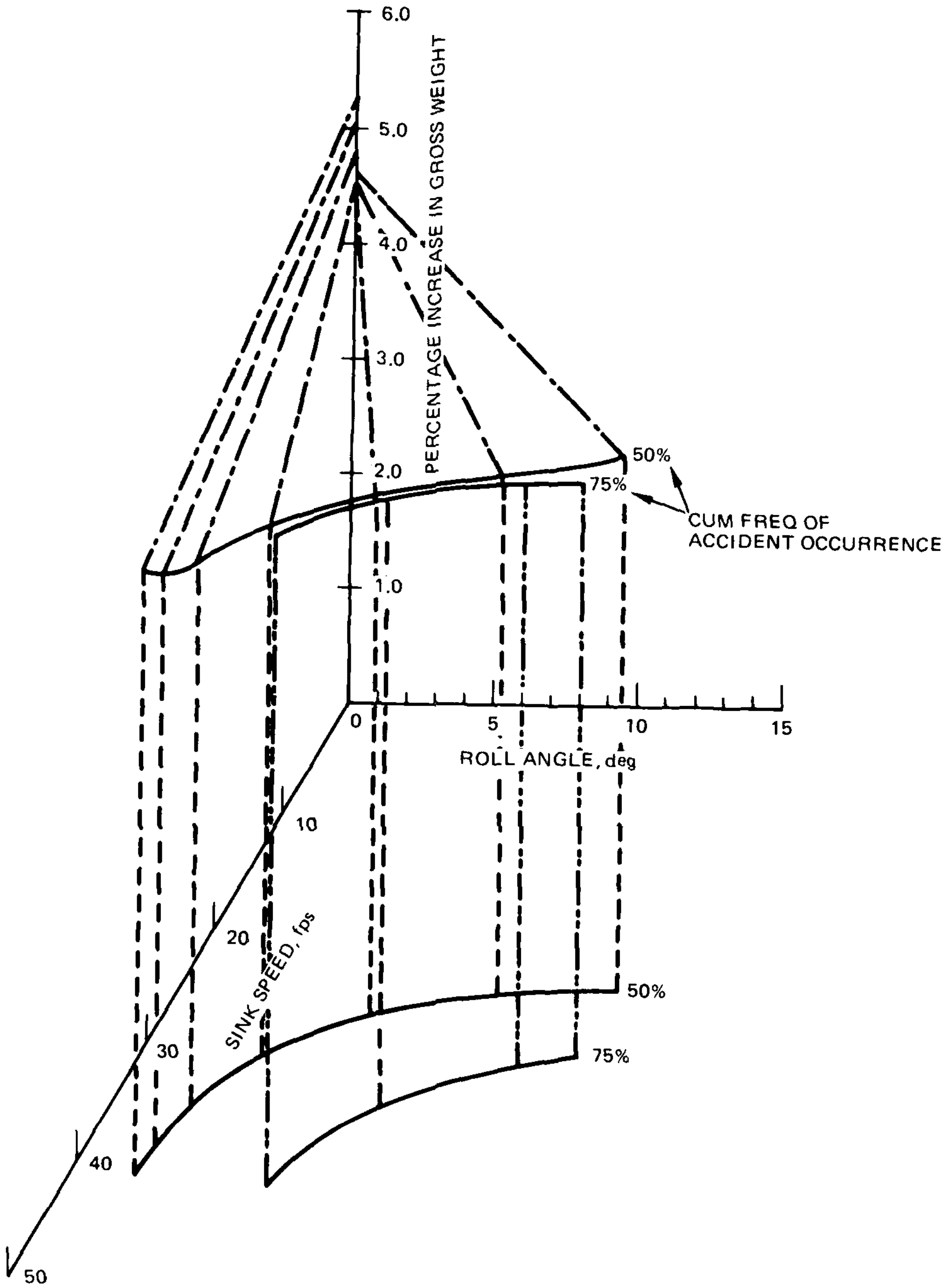

Figure 93. Percentage increase in gross weight of retractable uncoupled landing gear configuration for 50 and 75 percent cumulative frequency of occurrence of sink speed and roll angle for survivable helicopter accidents.

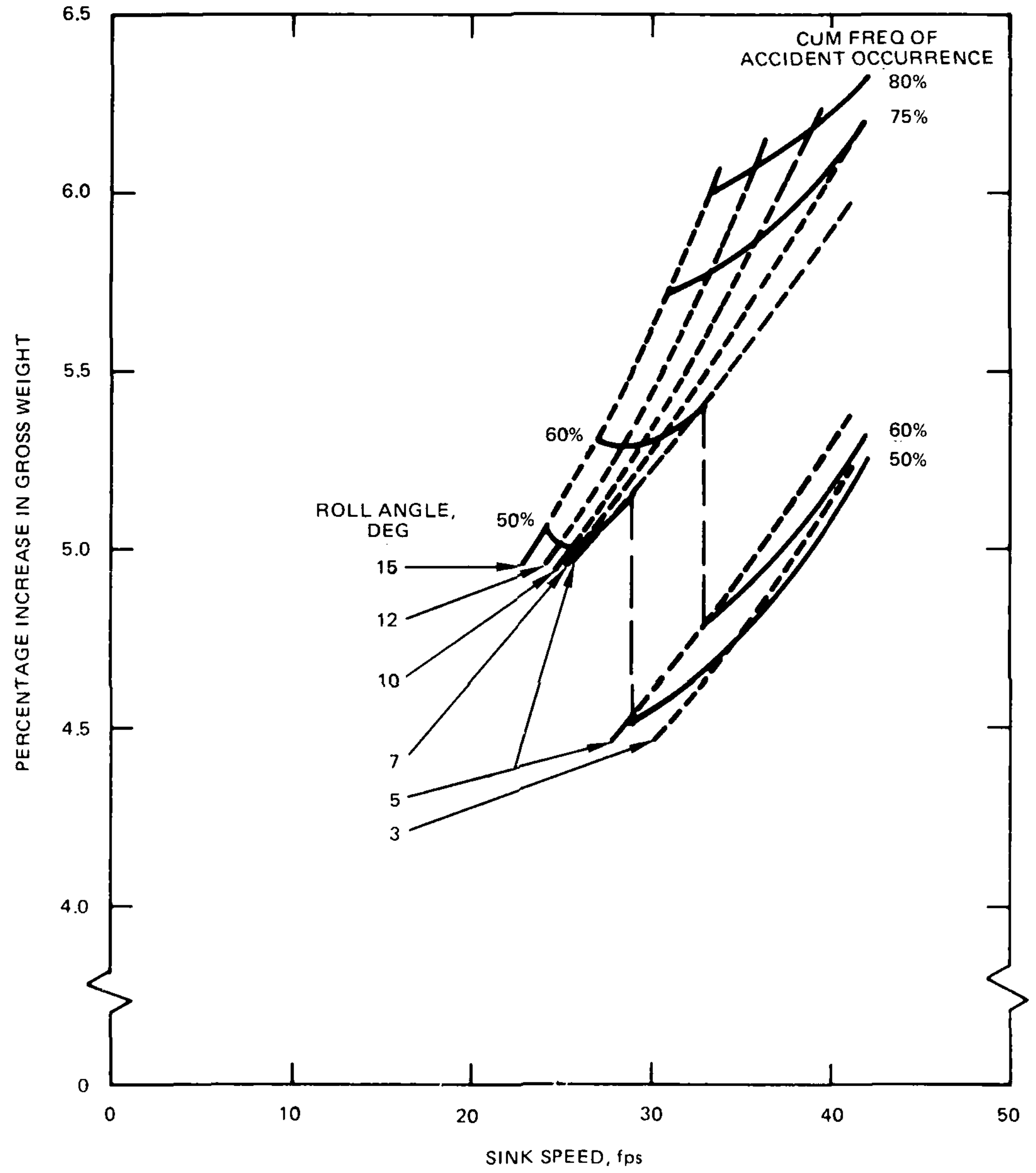

Figure 6?. Percentage increase in gross weight of retractable coupled landing gear configuration for 50, 60, 75 and 80 percent cumulative frequency of occurrences of survivable helicopter accidents.

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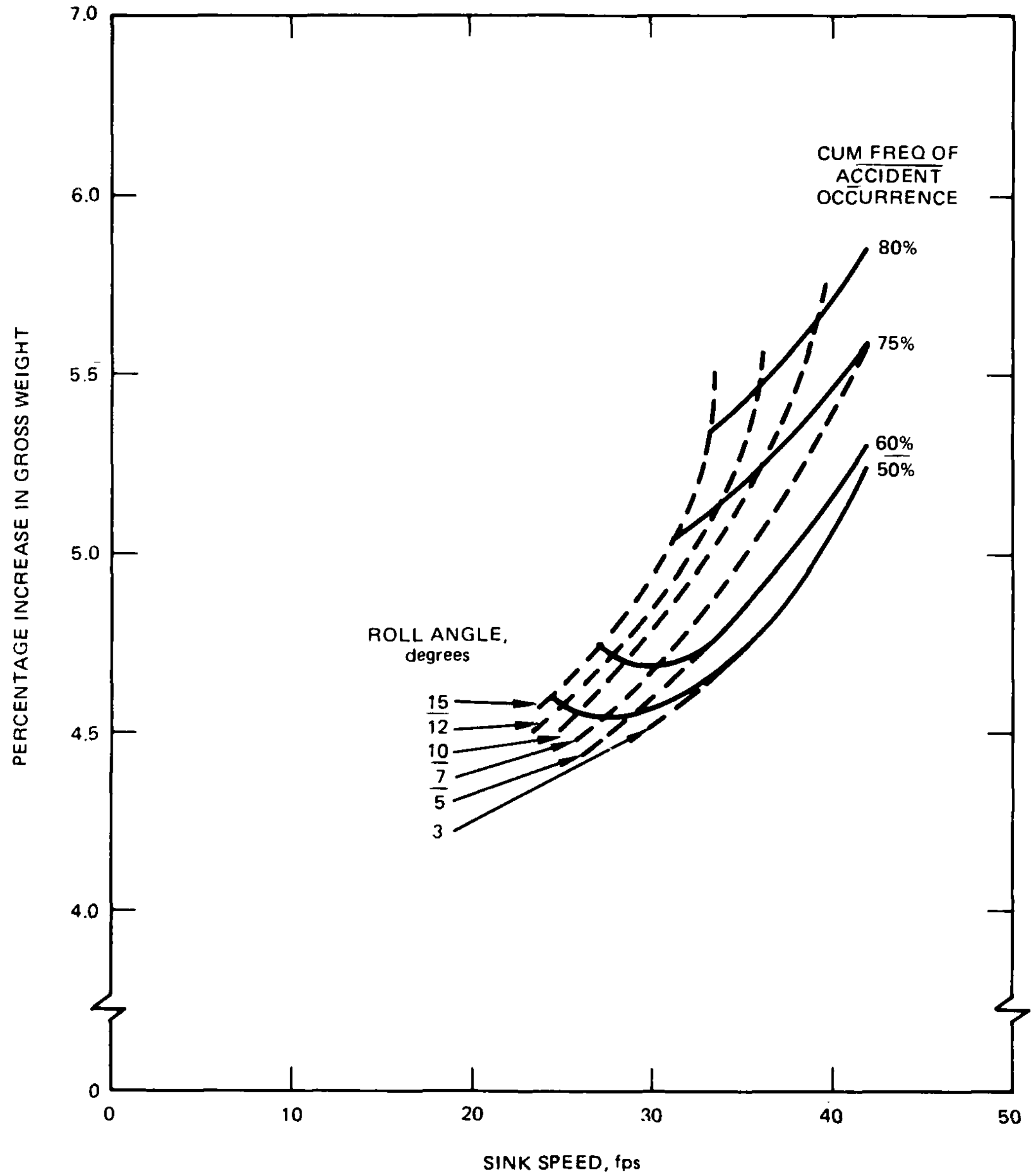

Figure 95. Percentage increase in gross weight of retractable uncoupled landing gear configuration for 50, 60, 75 and 80 percent cumulative frequency of occurrence of survivable helicopter accidents.

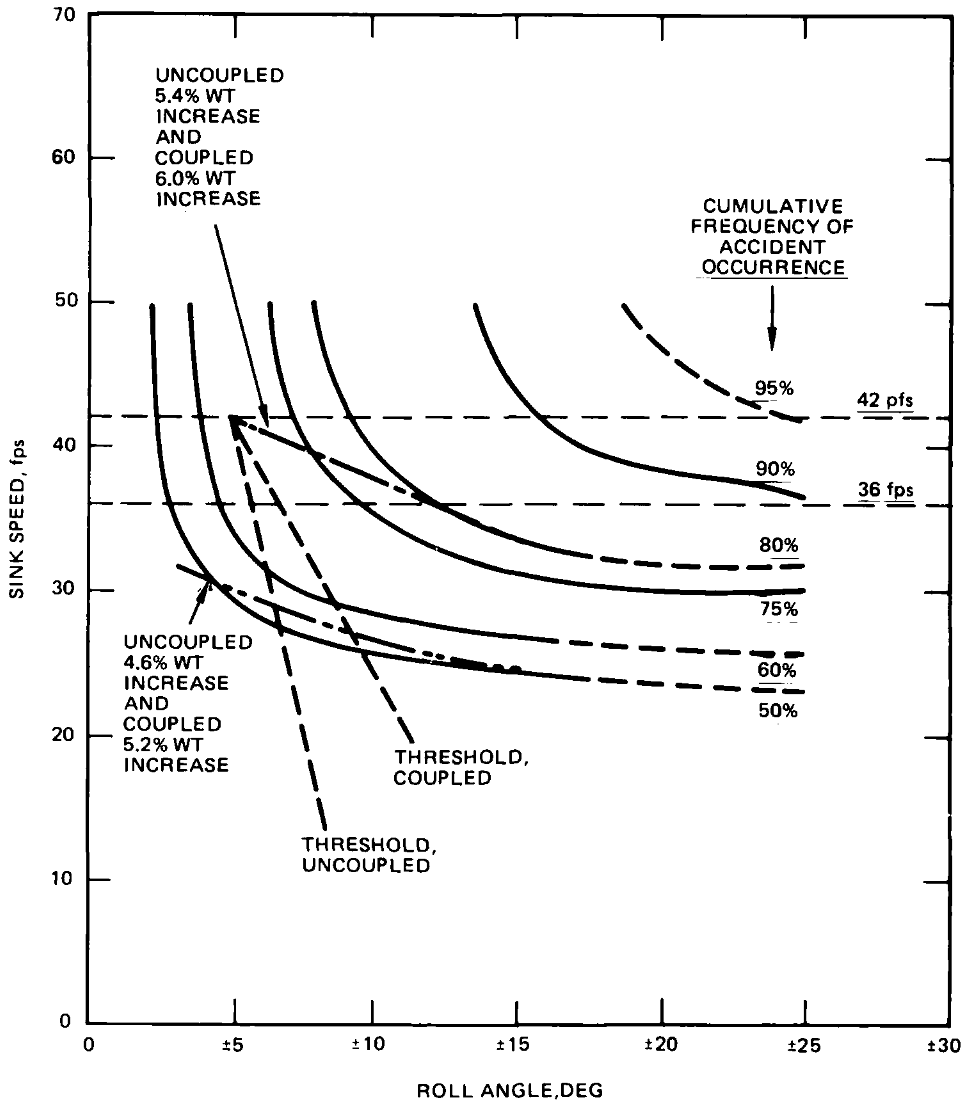

Figure 96. Representative bounds, and minimum thresholds, of the percentage increase in helicopter gross weight with cumulative frequency of survivable accident occurrence.

maximum cumulative frequency for a weight effective design of each gear configuration. The coupled threshold is the tangent to the 71-percent cumulative frequency curve at a sink speed of 36 fps. The uncoupled threshold is the tangent at 42 fps to the 67.4 percent cumulative frequency curve. The parameters of the point of tangency are the criteria for a weight effective design. The optimization of the parameters for a given cumulative frequency of accident occurrence involves a trade-off between roll angle and sink speed,

and percentage increase in gross weight. Further implications of the data presented in Figure 96 are given below:

- The two designs are equally weight efficient for crash impact at 42 fps and 5.0 degree roll angle.

- The cumulative frequency of accident occurrence for both designs is 67.4 percent with a weight increment of 5.4 percent over the baseline at 42 fps and ±5.0 degree roll angle.

- The weight effective design of the uncoupled landing gear configuration is at 42 fps and ±5.0 degree roll angle with a maximum cumulative frequency of accident occurrence of 67 percent and a weight increment of 5.4 percent.

- The weight effective design of the coupled landing gear configuration is at 36 fps and ±7.5 degree roll angle with a maximum cumulative frequency of accident occurrence of 71 percent and a weight increment of 5.8 percent.

To compare the equivalence of the two design criteria, comparative sink speeds with the corresponding roll angles, cumulative frequency of accident occurrences and the weight increments are presented in Table 35. The design criteria are for minimum percentage increases in gross weights. The helicopter with the coupled landing gear, therefore, encompasses 4 percent more accidents for 0.4 percent higher gross weight than the helicopter with the uncoupled landing gear.

8.4 COST TREND TABLES

The cost trend tables identify the cost of the incremental weight required to make the standard helicopter crashworthy and the probable cost of replacing the crew in the event of a fatal accident for the given sink speed. The cost trend tables are constructed from the incremental weight data in the weight trend tables (Tables 20 through 28). The incremental weight is that required to provide a survivable environment under crash conditions.

The basis for the cost trend tables is the procurement cost of the incremental weights. Typically, the procurement cost in 1984 for the fuselage is $182.00 per pound and that of the landing gear with the crew seats is $238.00 per pound. The total cost of the additional weights of the fuselage, crew seats and landing gear is shown in Column 5 of Tables 36 and 37.

The cost of replacing the crew is based on the cost of training an aviator (Reference 9). The cost of initial entry is estimated at $125,000 in 1981 dollars. With 5.8 percent inflation, the cost of initial entry in 1984 will be $148,000. Adding 35 percent for the "costs associated with 3 to 4 years of on-the-job training required to refine and maintain proficiency in skills," the training cost per aviator is conservatively estimated at $200,000. The "probable cost of

TABLE 35. DESIGN CRITERIA BASED ON WEIGHT EFFECTIVENESS

Landing Gear	Design Criteria		Cumulative Frequency of Accident Occurrence, %	Increase in Gross Weight, %
	Sink Speed, fps	Roll Angle, degrees		
Coupled	36	±7.5	71.0	5.8*
Uncoupled	36	±5.5	65.0	5.0
Coupled	42	±1.0	39.0	5.1**
Coupled	42	< ±5.0***	67.4	5.9
Uncoupled	42	±5.0	67.4	5.4*

*Recommended design criteria for the two landing gear configurations based on weight effectiveness only.

**This is not a weight effective design from the point of view of accident occurrences, but has been included for comparison only.

***The roll angle is just greater than ±5.0 degrees.

TABLE 36. COST TREND TABLE FOR CRASH IMPACT OF HELICOPTER WITH COUPLED RETRACTABLE LANDING GEAR

Sink Speed (fps)	Δ Weight, Fuselage (lb)	Δ Weight, Crew Seat + LG (lb)	Δ Cost, Fuselage ($)	Δ Cost, Crew Seat + LG ($)	Total Δ Cost ($)	Probable Cost of Replacing Crew	Total Cost ($)
<u>0-Degree Roll</u>							
42	348	133	63,684	31,654	95,338	20,000	115,338
36	304	126	55,328	29,988	85,316	28,000	113,316
30	284	116	51,688	27,608	79,296	52,000	131,296
20	274	78	49,868	18,564	68,432	180,000	248,432
15	268	69	48,776	16,422	65,198	68,000	133,198
<u>5-Degree Roll</u>							
42	348	228	63,336	54,264	117,600	20,000	137,600
36	312	216	56,784	51,408	108,192	28,000	136,192
30	293	197	53,326	46,886	100,212	52,000	152,212
20	274	138	49,868	32,844	82,712	180,000	262,712
15	268	117	48,776	27,846	76,622	68,000	144,622
<u>10-Degree Roll</u>							
42	348	264	63,336	62,832	126,168	20,000	146,168
36	316	250	57,512	59,500	117,012	28,000	145,012
30	294	213	53,508	50,694	104,202	52,000	156,202
20	274	148	49,868	35,224	85,092	180,000	265,092
15	268	120	48,776	28,560	77,336	68,000	145,336
<u>15-Degree Roll</u>							
42	348	301	63,336	71,638	134,974	20,000	154,974
36	324	265	58,968	63,070	122,038	28,000	150,038
30	295	232	53,690	55,216	108,906	52,000	160,906
20	274	158	49,868	37,604	87,472	180,000	267,472
15	268	125	48,776	29,750	78,526	68,000	146,526

TABLE 37. COST TREND TABLE FOR CRASH IMPACT OF HELICOPTER WITH UNCOUPLED RETRACTABLE LANDING GEAR

Sink Speed (fps)	Δ Weight, Fuselage (lb)	Δ Weight, Crew Seat + LG (lb)	Δ Cost, Fuselage ($)	Δ Cost, Crew Seat + LG ($)	Total Δ Cost ($)	Probable Cost of Replacing Crew	Total Cost ($)
0-Degree Roll							
42	348	133	63,684	31,654	95,338	20,000	115,338
36	304	126	55,328	29,988	85,316	28,000	113,316
30	284	116	51,688	27,608	79,296	52,000	131,296
20	274	78	49,868	18,564	68,432	180,000	248,432
15	268	69	48,776	16,422	65,198	68,000	133,198
5-Degree Roll							
42	368	134	66,976	31,654	98,630	20,000	118,630
36	336	128	61,152	30,464	91,611	28,000	119,616
30	312	119	56,784	28,322	85,106	52,000	137,106
20	302	86	54,964	20,468	75,432	180,000	255,432
15	297	74	54,054	17,612	71,666	68,000	139,666
10-Degree Roll							
42	404	148	73,528	35,224	108,752	20,000	128,752
36	363	140	66,066	33,320	99,386	28,000	127,386
30	315	131	57,330	31,178	88,508	52,000	140,508
20	305	96	55,510	22,848	78,358	180,000	258,358
15	295	82	53,690	19,516	73,206	68,000	141,206
15-Degree Roll							
42	421	156	76,622	37,128	113,750	20,000	133,750
36	383	146	69,706	34,748	104,454	28,000	132,454
30	321	138	58,422	32,844	91,266	52,000	143,266
20	307	102	58,874	24,276	80,150	180,000	260,150
15	296	86	53,872	20,468	74,340	68,000	142,340

replacing crew" if the helicopter were not crashworthy, given in Column 6 of Tables 36 and 37, represents the product of the total cost of $400,000 to replace a crew of two and the frequency of accident occurrence at the given sink speed. The frequency of accident occurrence for each sink speed is taken from the cumulative frequency of accident occurrence curve shown in Figure 89. The "total cost" of Column 8 of Tables 36 and 37 represents the cost of replacing all of the additions made to the airframe for crashworthiness and that of replacing the crew based on the frequency with which accidents occur at these sink speeds.

8.5 COST TREND CURVES

The cost trend curves shown in Figures 97 and 98 show the cost of replacing airframe and crew for the case of the coupled retractable landing gear. The costs of replacement for the case of the uncoupled retractable landing gear are shown in Figures 99 and 100. The variation with pitch angle is not shown in these figures because it is minimal as the weight trend curves show. The cost trend curves are based on the approach proposed in Reference 10 for determining optimum increases in cost and weight to provide the desired crashworthiness against diminishing returns of increased probability of crash survival.

The cost, X, of additions to the airframe with coupled landing gear to increase crashworthiness increases almost linearly through all sink speeds (Figure 97). The probable cost, Y, of replacing the crew for a noncrashworthy helicopter reflects the high frequency with which accidents occur between 20 and 30 fps. The total cost (X + Y) of the airframe incremental weight and the crew for the coupled landing gear configuration is shown in Figure 98 as a function of sink speed and roll angle. The cost is the sum of the airframe cost and the probable cost of replacing the crew. The total cost (X + Y) increases with roll angle and is lowest at 0 degree roll impact for all sink speeds. The minimum point on the total cost curves for ± 5 and ± 10 degree roll is at a sink speed of 39 fps. The minimum cost for the ± 15 degree roll occurs for 38 fps.

The largest increment in cost occurs between 0 and 5 degree roll, after which the increment is uniform for increasing roll angle. The large increment between 0 and 5 degrees is due to the inclusion of the torque tube.

The corresponding plots for the uncoupled landing gear are shown in Figures 99 and 100. The plot for the total cost (X + Y) of replacing all airframe components and the crew, shown in Figure 100, shows that the lowest cost for 0-, 10-, and 15-degree roll occurs for a sink speed of 39 and 38 fps, whereas the lowest cost for 5-degree roll is for a sink speed of 42 fps.

8.6 COST EFFECTIVE DESIGN CRITERIA

The cost effectiveness of the two designs is not apparent from Figures 98 and 100. Separately, for each of the roll angles a cost effective design exists. For the coupled landing gear configuration, the cost effective design for all

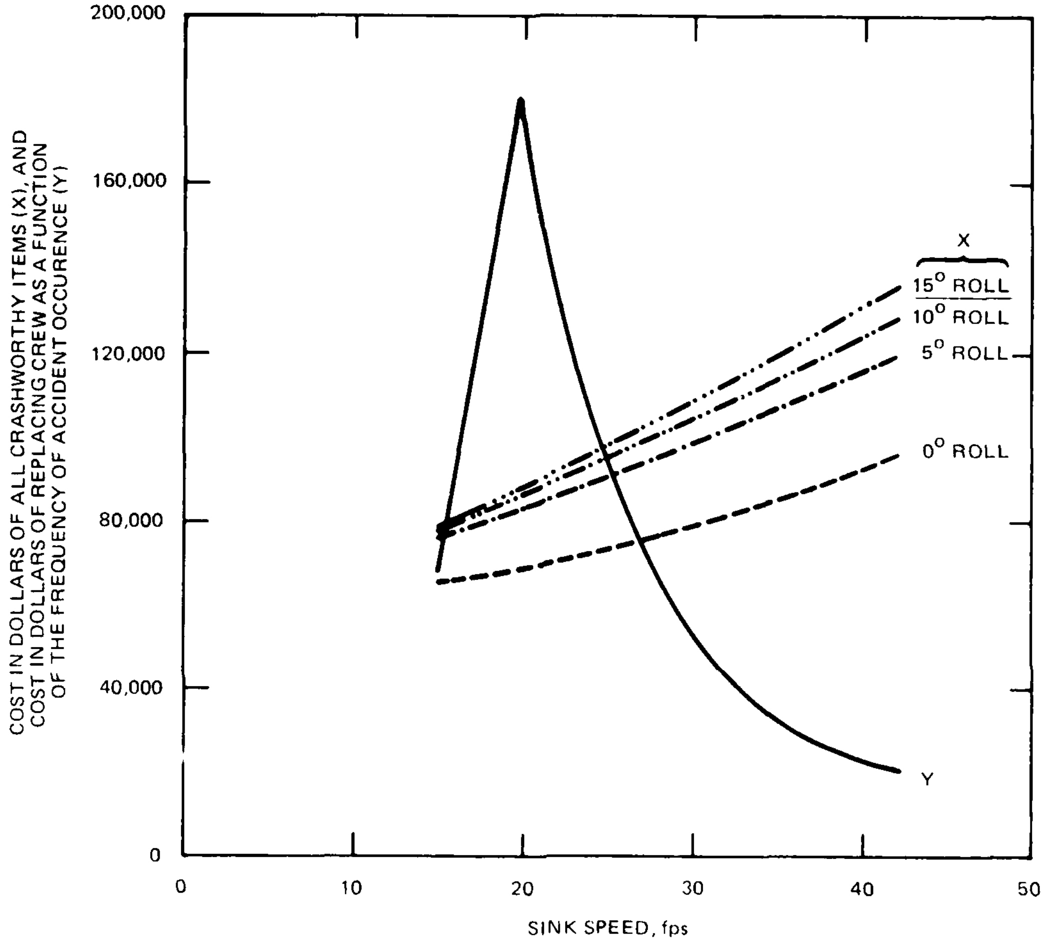

Figure 97. Cost of crashworthy airframe and of replacing crew for helicopter with coupled landing gear.

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B

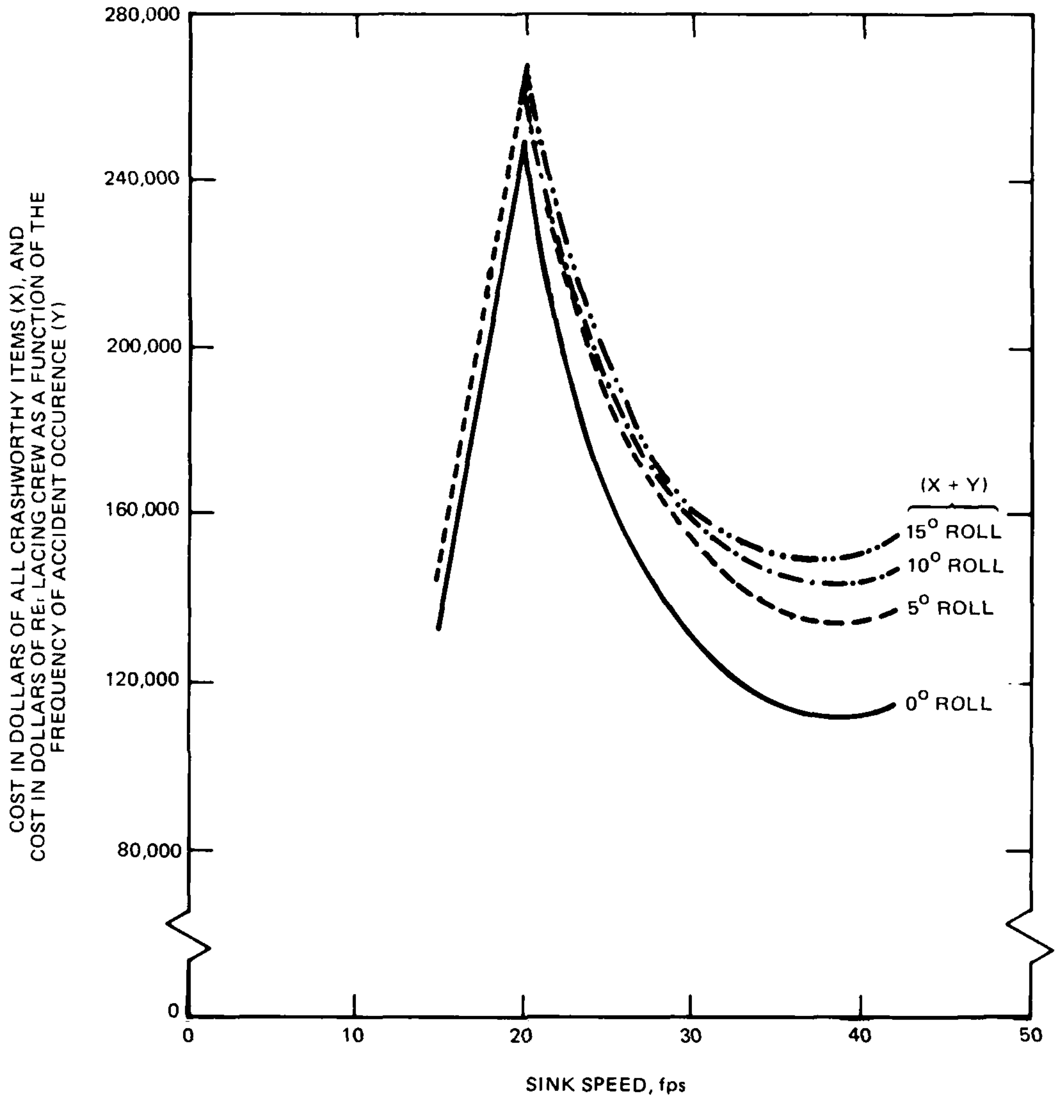

Figure 98. Cost trend curves for helicopter with coupled landing gear.

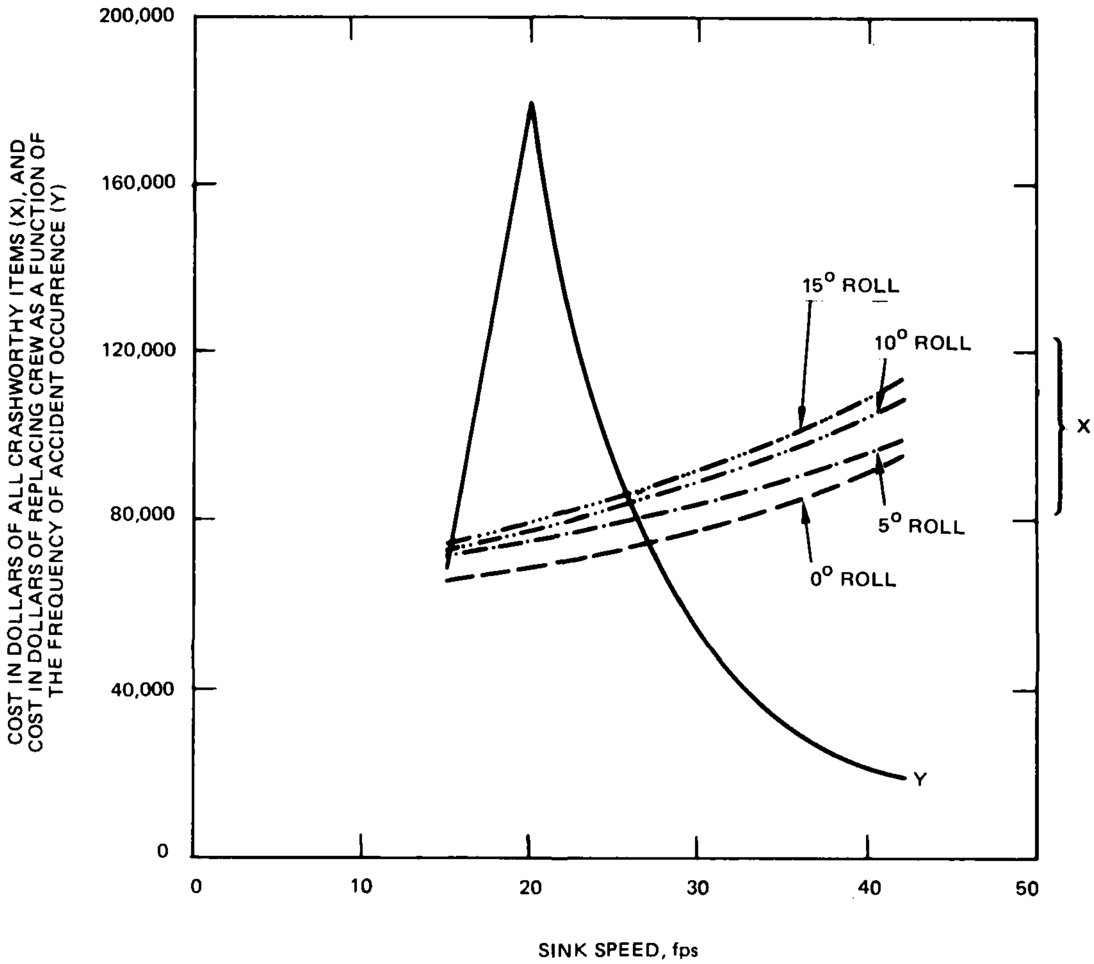

Figure 99. Cost of crashworthy airframe and of replacing crew for helicopter with uncoupled landing gear.

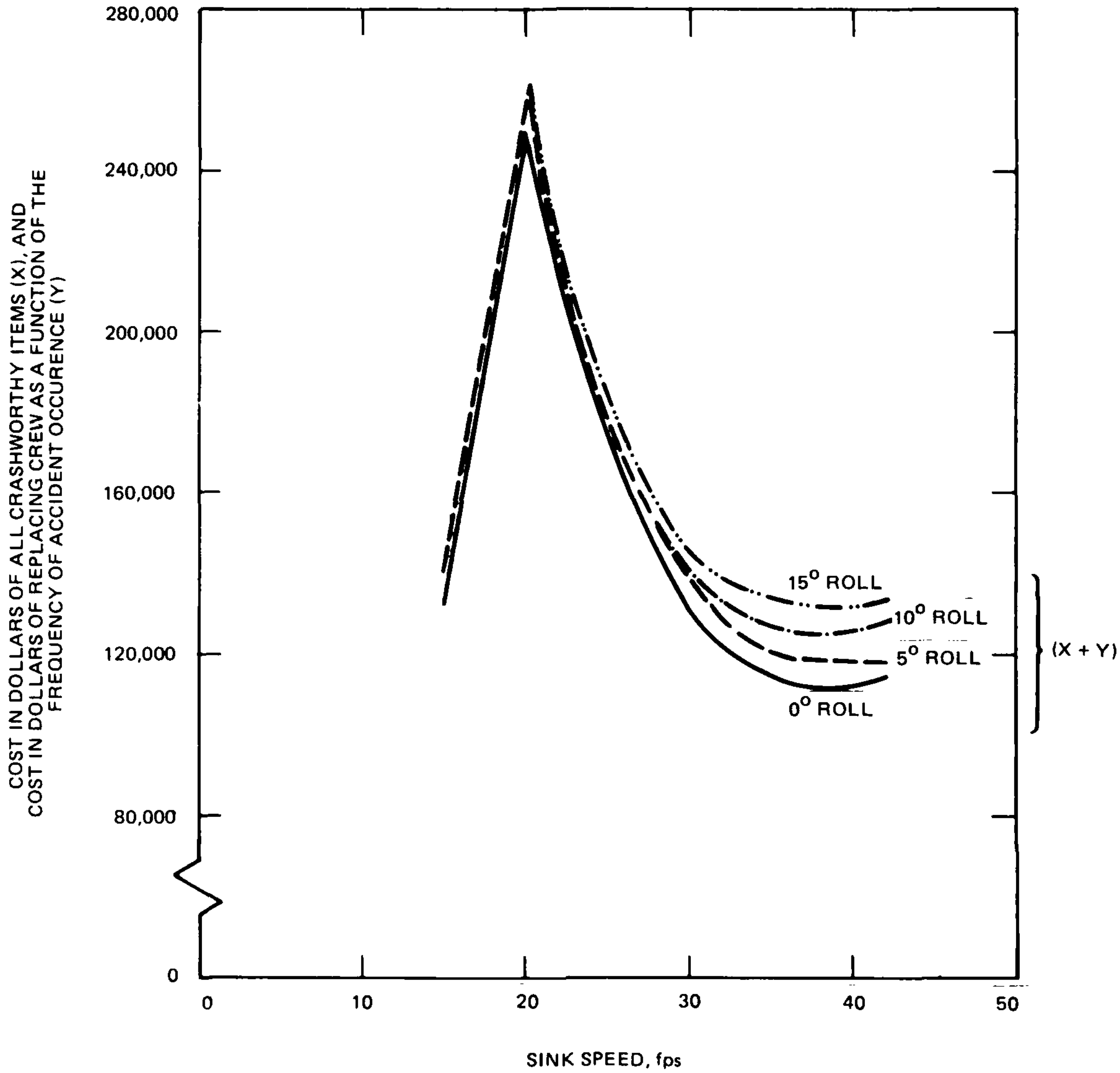

Figure 100. Cost trend curves for helicopter with uncoupled landing gear.

roll angles is at a sink speed of 38 or 39 fps. In contrast, for all the uncoupled landing gear configuration, the cost effective design for ±10 and ±15 degree roll angles is at 38 fps but for ±5 degree roll angle is at 42 fps.

The costs of the potential design criteria for each roll angle are given in Table 38. On the basis of cost alone, the crash impact condition of 42 fps and ±5 degree roll angle suggests itself as the design criterion for the uncoupled landing gear configuration. However, for the coupled landing gear configuration several possibilities exist; these are discussed in the following section.

TABLE 38. POTENTIAL DESIGN CRITERIA BASED ON COST EFFECTIVENESS

Landing Gear	Roll Angle, degrees	Sink Speed, fps	Cumulative Frequency of Accident Occurrence, %	Cost, $
Coupled	0	39	28.7	112,000
Uncoupled	0	39	28.7	112,000
Coupled	< ±5*	39	65.7	134,000
Uncoupled	±5	42	67.4	118,630
Coupled	±10	39	78.6	144,000
Uncoupled	±10	38	77.9	125,200
Coupled	±15	38	85.7	150,000
Uncoupled	±15	38	85.7	132,000

*The roll angle is just greater than ±5 degrees.

8.7 DESIGN CRITERIA

The design of the crashworthy landing gears, both retractable and fixed with torque tube, met the design requirements of sink speed, roll angle and pitch angle within the design gross weight of 10,000 pounds. The same requirements were met by the uncoupled retractable and fixed landing gears. The difference in the weights between the two designs is due to the lighter landing gear but heavier fuselage when torque tube coupling is absent. The helicopter design with the coupled landing gear has a heavier landing gear, whereas that with the uncoupled landing gear has a heavier fuselage underfloor structure. The weight effective designs of the two helicopter configurations have been discussed in Section 8.3 and the design criteria presented in Table 35. The difference in costs between the two designs varies with the design criterion because fuselage fabrication cost is lower than the cost of landing gear fabrication. The potential cost effective design criteria are presented in Table 38.

The cumulative frequencies of occurrences of various sink speeds and roll angles are shown in Figures 89 and 91. A 36 fps impact occurs with a cumulative frequency of 89 percent and a 42 fps impact with 95 percent. Similarly, a ±5 degree roll impact occurs with a cumulative frequency of 71 percent, and ±7.5, ±10 and ±15 degree roll impacts with 80, 85 and 93.5 percent, respectively. The percentages of cumulative frequency of the product of each of two sink speeds and four roll angles are given in Table 39.

The design criteria for the two designs are presented below, and the consequences of these recommendations are discussed in Section 8.8.

TABLE 39. CUMULATIVE FREQUENCY OF ACCIDENT OCCURRENCE (SINK SPEED x ROLL ANGLE)

Sink Speed, fps	Roll Angle, degrees	Cumulative Frequency of Accident Occurrence
42	±5	0.6745
42	±7.5	0.7600
42	±10	0.8075
42	±15	0.8882
36	±5	0.6319
36	±7.5	0.7096
36	±10	0.7540
36	±15	0.8293

8.7.1 Coupled Retractable Landing Gear

The weight effective design criteria, shown in Table 35, for the coupled landing gear are given as a sink speed of 36 fps and a roll angle of ±7.5 degrees. In contrast, the cost effective design criterion, shown in Table 38, can be one of several. If the choice is based on the highest possible sink speed to maximize the cumulative frequency of accident occurrence, the cost effective design criteria for the coupled landing gear are given as a sink speed of 39 fps and a roll angle of ±10 degrees. The cost effective criteria are close to the weight effective criteria but with an increased cumulative frequency of accident occurrence of 78.6 percent. In terms of "standard" sink speed values, the recommended criteria are

Velocity	Roll Angle	Pitch Angle
42 fps	0 to ±7.5 deg	-5 to ±15 deg
36 fps	0 to ±15 deg	-5 to +15 deg
30 fps and less	greater than ±15 deg	-5 to +15 deg

The recommended criteria result in a 6.3 percent increase in gross weight over the standard helicopter for a cumulative frequency of accident occurrence of 83 percent.

AD-A158 816 ADVANCED TECHNOLOGY HELICOPTER LANDING GEAR PRELIMINARY DESIGN INVESTIGAT..(U) HUGHES HELICOPTERS INC CULVER CITY CA J K SEN ET AL. JUL 85 HHI-84-284 3/3

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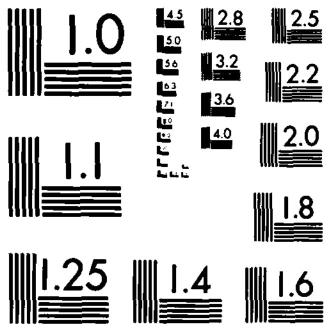
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

8.7.2 Uncoupled Retractable Landing Gear

The weight effective design criteria given in Table 35 for the uncoupled landing gear correspond exactly to the cost effective criteria if the basis for the choice is the highest possible sink speed which will maximize the cumulative frequency of accident occurrence. The criteria are for a sink speed of 42 fps and a roll angle of ±5 degrees for a 5.4 percent increase in gross weight and a cumulative frequency of accident occurrence of 67.5 percent. However, a 5.4 percent increase in gross weight corresponds to a sink speed of 36 fps and a roll angle of ±10 degrees, which results in a cumulative frequency of accident occurrence of 75.4 percent. The recommended criteria are therefore

Velocity	Roll Angle	Pitch Angle
42 fps	0 to ±5 deg	-5 to ±15 deg
36 fps	0 to ±10 deg	-5 to +15 deg
30 fps and less	greater than ±15 deg	-5 to +15 deg

8.8 DISCUSSION

The criteria for the coupled landing gear encompass 83.0 percent of all accidents with a 6.3 percent increase in gross weight. The total cost for increasing crashworthiness per aircraft and replacing the crew in case of an accident is $150,974.

The criteria for the uncoupled landing gear encompasses 75.4 percent of all accidents with a 5.4 percent increase in gross weight and a total cost of $127,386 per aircraft. This results in a weight savings of 88 pounds and a cost savings of $24,000 over the coupled landing gear criteria.

From the above discussion, it is evident that the helicopter with the uncoupled landing gear is both weight and cost effective. The trade-off between the two criteria is between increased survivability (83.0 percent as against 75.4 percent) and a lighter helicopter (88 pounds in weight savings) and a cost effective design ($24,000 in savings). The helicopter with the uncoupled landing gear is 107 pounds lighter than that with the coupled landing gear when the cross tube is made of graphite/epoxy material.

The criteria for the uncoupled landing gear are attractive because they result in a lighter and less expensive helicopter which is both cost and weight effective. The increased agility of a lighter helicopter can compensate for the decreased survivability level of these criteria.

The recommendation is for a helicopter with an uncoupled retractable landing gear with a parasitic drag of 10.16 square feet with the gear retracted and designed to meet the crashworthiness requirements of Table 40. This results in:

a. A weight effective design

b. A cost effective design

c. An increased weight of only 5.24 percent over the standard helicopter when the cross tube is made of graphite/epoxy material

d. 75.4 percent survivability of all accidents

TABLE 40. RECOMMENDED DESIGN CRITERIA

Impact Velocity, fps	Range of Roll Angles, degrees	Range of Pitch Angles, degrees
42	0 to ±5	-5 to +15
36	0 to ±10	-5 to +15
30 and less	Greater than ±15	-5 to +15

SECTION 9

DESIGN UPDATE

9.1 THE DESIGNS

The design update was completed in the Phase III study and incorporated the recommended design criteria of Table 40. The most significant result of the Phase II study was the decision to decouple the trailing arms of the main landing gear. This change resulted in reduced component loading, helicopter weight and design complexity. The changes made for the major landing gear components are discussed below.

9.1.1 Cross Tube

The cross tube is the supporting member for the trailing arms of the main landing gear. The cross tube is designed using 300M alloy steel and its geometry is shown in Figure 101. The cross tube is lighter than the torque tube, shown in Figure 11, which is its counterpart in the coupled landing gear design. Unlike the torque tube, the cross tube is not designed to transmit the high torsional loads of unsymmetrical crash impact but merely provides the pivot for the trailing arms and restrains their movement only to rotation about a lateral axis of the helicopter. Consequently, the cross tube has a smaller cross section than the torque tube and does not possess the splines to engage the trailing arms. The nominal outside diameter of the cross tube is 4.0 inches with a wall thickness of 0.150 inch for a crash impact at 42 fps and 15-degree roll. The trailing arms mount at each end of the cross tube on bearing surfaces (Figure 17).

With the reduced loading on the cross tube, it can be designed using graphite/epoxy in the updated design. The cross tube will have a graphite/epoxy center section and steel end-fittings. The steel end-fittings are bonded to the center section with a 3-inch overlap. The graphite/epoxy cross tube is 56 inches long and has a nominal outside diameter of 4.0 inches with a wall thickness of 0.200 inch for a crash impact at 42 fps and 15-degree roll. The dimensions of the end-fittings, 12 inches in length at each end, are the same as those of the steel cross tube. The bonding of the end-fittings to the center section and the mounting of the trailing arms to the cross tube are shown in Figure 21. The composite cross tube is 19 pounds lighter than the steel cross tube, as given in Table 11.

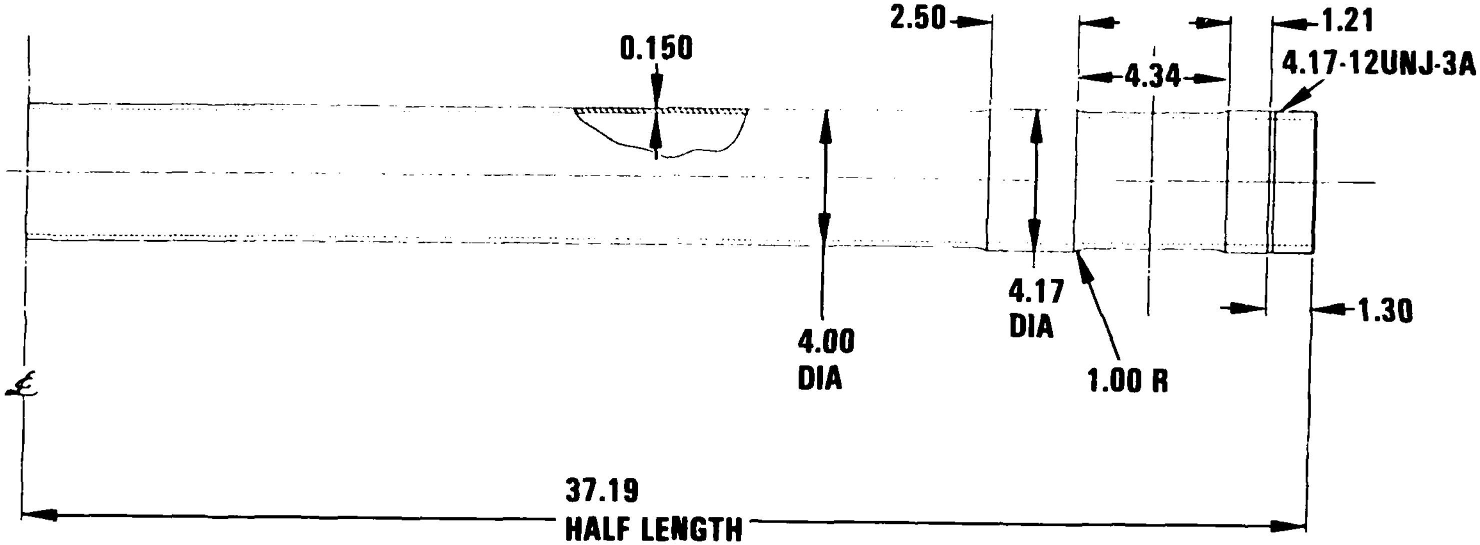

Figure 101. 300M alloy steel cross tube of the crashworthy uncoupled main landing gear.

9.1.2 Main Gear Trailing Arms

The changes made for the cross tube directly influence the design of the trailing arm. The elimination of the torsional load transfer requirement, combined with elimination of the splines, results in a reduction of the cross section of the entire trailing arm. The redesigned trailing arm (Figure 102) weighs 25.6 pounds compared with the old trailing arm (Figure 12) weight of 37.6 pounds. The trailing arm is designed to be constructed of 300M alloy steel.

9.1.3 Shock Struts, Main and Tail

The shock strut combines the requirements of the oleo, the energy-absorbing strut and the retraction actuator. The design specifications, therefore, are those of the landing gear geometry, stated in Section 3.3 and shown in Figures 9 and 10; the ground resonance requirements of Section 3.9; and the energy-absorbing requirements. The desired energies to be absorbed by the main shock strut, with a maximum available stroke of 24 inches, were specified in terms of the following main strut loadings:

a. During crash 43,400 pounds

b. 2g hard landing 12,100 pounds

c. Static position 6,050 pounds

Several design concepts were identified by Menasco, Inc. of Burbank, California. The design scheme selected for the main strut was one which satisfies all the above requirements and one with the lowest inertia of the stroking section, which reduces the load impulses induced by the inertia of the shock struts during crash impact. An additional requirement was simplicity of design. The main shock strut is shown in Figure 103. It is made of 300M alloy steel and weighs 128 pounds. The tail shock strut is similar in design but with a strut load of 62,300 pounds during crash and a stroke of 12 inches.

9.1.4 Trailing Arm, Tail Gear

The retractable tail gear design update includes only minor changes from the trailing arm design shown in Figure 13. The revised trailing arm design, shown in Figure 104, has a slightly increased torsional capability. The trailing arm of the fixed tail gear has been refined to include a yoke to attach it to the fuselage. This change was made to improve maintainability and simplify assembly. The trailing arm of the fixed tail gear is shown in Figure 105.

9.2 LANDING GEAR WEIGHT

The weights of the retractable and fixed uncoupled landing gears are given in Table 41 for the recommended design criteria of Table 40. These retractable and fixed gears are 94 pounds and 47 pounds heavier than the standard (non-crashworthy) gears. To absorb the crash impact energy, however, the fuselage,

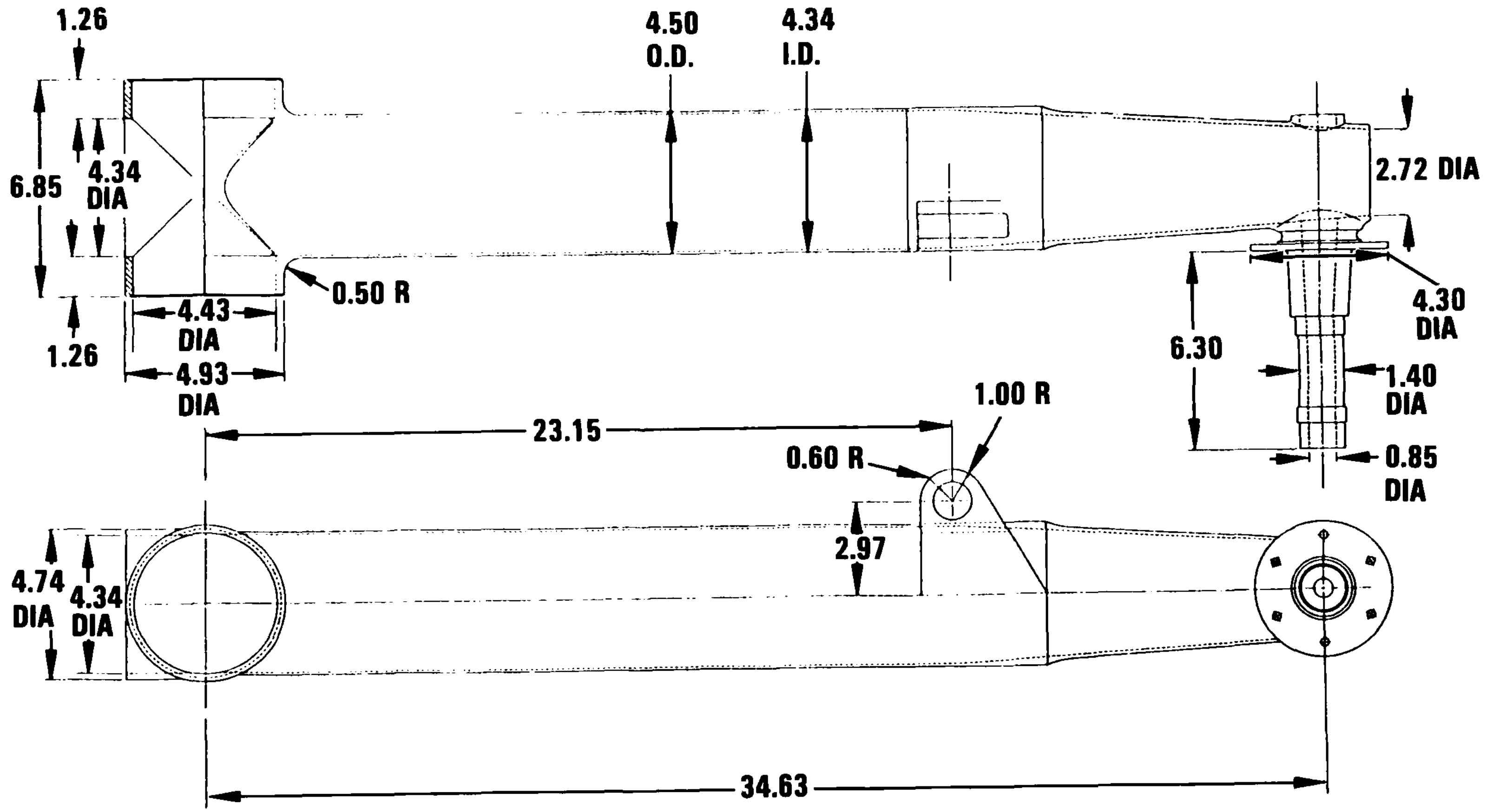

Figure 102. Trailing arm of crashworthy uncoupled main landing gear.

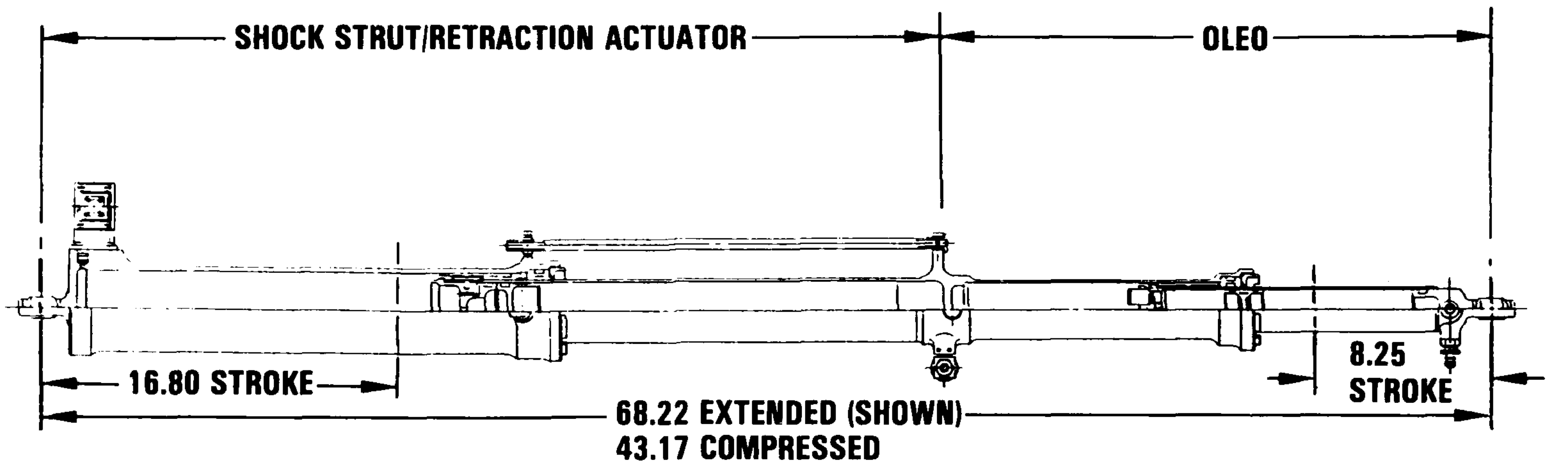

Figure 103. Combined shock strut/oleo for crashworthy uncoupled main landing gear.

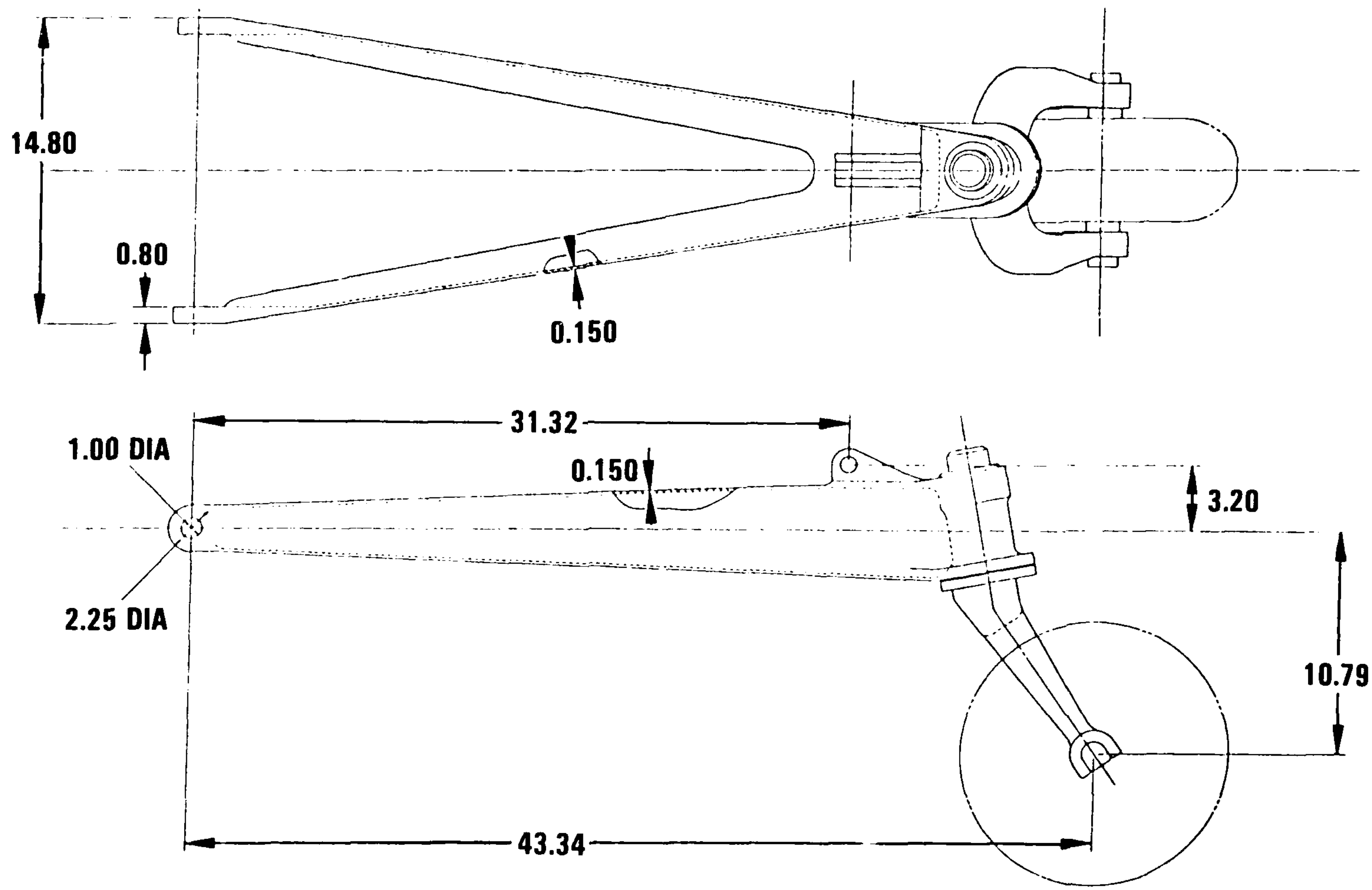

Figure 104. Tail gear trailing arm of the retractable crashworthy uncoupled landing gear.

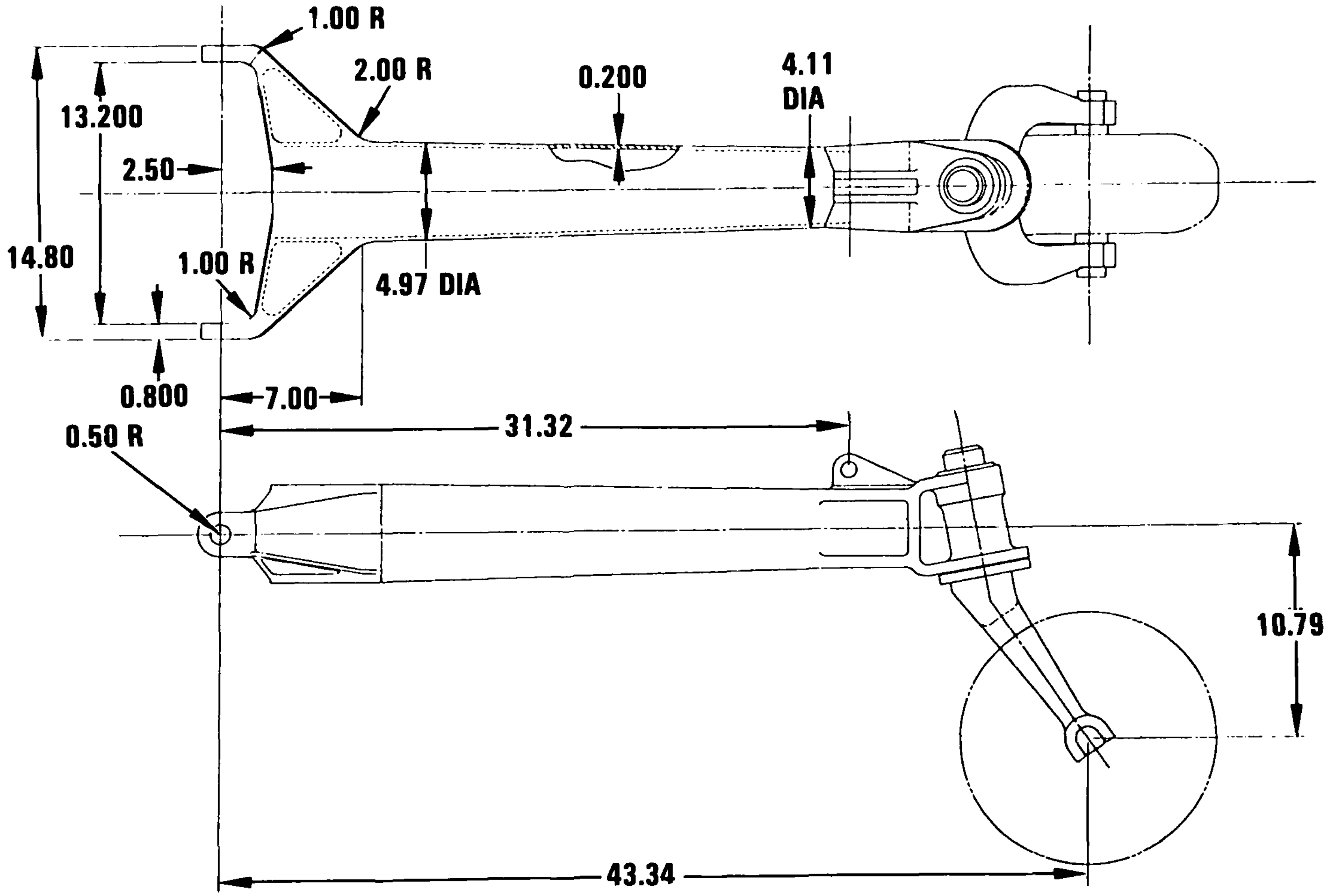

Figure 105. Tail gear trailing arm of the fixed crashworthy uncoupled landing gear.

TABLE 41. LANDING GEAR COMPONENT WEIGHTS IN POUNDS FOR RECOMMENDED DESIGN

Component	Retractable		Fixed	
	MLG	TLG	MLG	TLG
Rolling Assembly	68	10	68	10
Cross Tube, Graphite/Epoxy	24	-	24	-
Gear-Fuselage Attachment Fittings	15	10	15	10
Trailing Arms	51	22	51	29
Shock Strut	124	20	107	12
Attachment Fittings	12	5	12	5
Controls	26	3	-	-
Subtotals	320	70	277	66
Totals	390		343	

seat, and fuel systems are strengthened by 397 pounds. The total increase in weight for the entire helicopter with the retractable landing gear is 491 pounds, and 5.24 percent, over the standard helicopters. The total gross weight of the helicopter with the retractable gear of the recommended criteria is shown in Table 42. If a steel cross tube replaces the graphite/epoxy cross tube, an addiitonal weight of 12 pounds is gained for the crash impact condition recommended as the design criterion. This results in a helicopter of 9868 pounds gross weight, which is 5.36 percent heavier than the standard helicopter.

9.3 DRAG ESTIMATE

The design did not result in any changes in the parasitic drag from that calculated in Phase I. The drag estimates are given in Table 5.

9.4 GROUND RESONANCE ANALYSIS

The changes in the design did not modify the requirements identified earlier in ground resonance analysis and described in Section 3.9.

TABLE 42. GROSS WEIGHT OF CRASHWORTHY HELICOPTER WITH RECOMMENDED DESIGN OF RETRACTABLE UNCOUPLED LANDING GEARS

Item	Helicopter Weight, Pounds
	Uncoupled LG
Crew (2)	500
Payload	1763
Fuel	1550
Tail Rotor	67
Body	986
Landing Gear	390
Exhaust	94
Nacelle	139
Fuel System	284
Armor	230
Furnishing	300
Mission Equipment	919
Common Weight	2634
Gross Weight	9856

9.5 MATERIAL TRADE-OFF STUDY

The material trade-off study identified the cross tube of the landing gear design as a candidate suited for composite design. This has been discussed in Section 9.1.1 and its influence in reducing the weight in Section 9.2.

9.6 COST

The cost of the landing gear with the uncoupled trailing arm design has been based on a parametric study of the AH-64 landing gear. The cost has been estimated from

a. Actual costs of wheels, brakes and tires

b. \$238 per pound for all fabricated structural hardware

c. Estimated cost on all shock struts based on current vendor prices for the AH-64 systems

The costs shown below are the selling prices based on 1000 ship sets with an 86 percent learning curve.

a.	Main Gear	\$17,482
b.	Main Shock Strut	\$51,420
c.	Tail Gear with Shock Strut	\$10,618

The estimated total cost of the landing gear is \$79,520.

9.7 MANUFACTURING PROCESS

The components of the landing gear, identified in Table 41, can be divided into three categories from the manufacturing and procurement point of view: specialized landing gear component items which are procured from their respective manufacturers, items which are fabricated by existing methods, and items which are fabricated of composite materials. Rolling assemblies, consisting of wheels, brakes and tires, and controls are specialized items procured from the respective manufacturers. The trailing arms, shock struts and attachment fittings are made of conventional materials and are fabricated according to existing methods.

The center section of the graphite/epoxy cross tube consists of ply orientations of $0°/\pm 45°/90°$ in percentages of 64/18/18, respectively. With the simple geometry of the cross tube, it is best manufactured by filament winding techniques. The end fittings are fabricated using existing metal technology and then bonded to the center section to complete the assembly of the cross tube.

9.8 RELIABILITY AND MAINTAINABILITY

The landing gear is simple with direct load paths for increased reliability and is designed to reduce maintenance costs. Some of the design features which enhance the reliability and maintainability are identified below:

- Simply articulated trailing arm design with dual-position landing gear

- Short direct load paths from gear attachment points to main fuselage
- A relatively constant geometry factor to achieve high stroke efficiency
- Combination of actuator and energy-absorbing strut which utilizes the stroking action as the retraction mechanism
- Minimizes degrees of motion involved in the stroking/retraction process
- Energy absorbed by the landing gear is optimized by allowing the fuselage to absorb as much energy as possible for a cost and weight effective design.
- Landing gear materials chosen are those readily available requiring existing and simple manufacturing processes.

SECTION 10

CONCLUSIONS AND RECOMMENDATIONS

Two crashworthy landing gear design configurations for a 10,000 pound LHX utility-class helicopter have been evaluated. Based on weight and cost trend curves, design criteria have been recommended and the preliminary designs of crashworthy retractable and fixed gears have been completed.

The specific requirements of the design are to meet crashworthiness requirements of impact velocity, roll angle and pitch angle. The requirements were satisfied in all cases through analyses by program KRASH. The approach taken to absorb the crash kinetic energy is the systems approach where the system of the landing gear, fuselage and stroking seat share the energy to make the impact survivable.

The first landing gear design configuration investigated was a design with a torque tube to couple the trailing arms of the gear in order to actuate the energy-absorbing shock strut of the upside gear in a nonsymmetrical crash condition. The second landing gear configuration was without the coupling of the torque tube. The difference in the crash impact behavior between the two designs is the additional energy that is absorbed by the fuselage with uncoupled gear for a nonsymmetrical impact.

Based on the weight sensitivity analysis, the uncoupled composite gear configuration has a weight advantage of nearly 0.7 percent of the gross weight in a one-to-one comparison. Additionally, the strokes of the down-side landing gear, fuselage and seat increase over that of the coupled gear in order to attenuate the same impact energy.

The design advocated is an uncoupled main landing gear with a graphite/epoxy cross tube and a pair of combination actuator/shock strut. The design criteria for the landing gear is based on weight trend curves and cost trend curves developed during the program. The design criteria recommended is cost- and weight-effective, and achieves a 75.4 percent survivability from all accidents.

The helicopter designed to the recommended criterion is 5.24 percent heavier than the standard noncrashworthy helicopter for a retractable gear configuration and 4.74 percent for a fixed gear configuration.

Based on the results of this effort, it is recommended that:

a. The uncoupled landing gear design be further refined on the basis of an optimum fuselage underfloor design, through KRASH analyses, in a trade-off study involving

- A higher loading fuselage design instead of the longer stroking fuselage design, which has been completed

- A two-stage load-limit design

b. A landing gear designed to the recommended criterion be fabricated and tested to correlate the test results with those of structural analysis.

Irrespective of the recommendation for further analyses, fabrication and testing of the landing gear should be pursued as a follow-on program.

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APPENDIX A

DETAIL PLOTS OF FUSELAGE DEFORMATIONS FROM PHASE II STUDY OF COUPLED LANDING GEAR

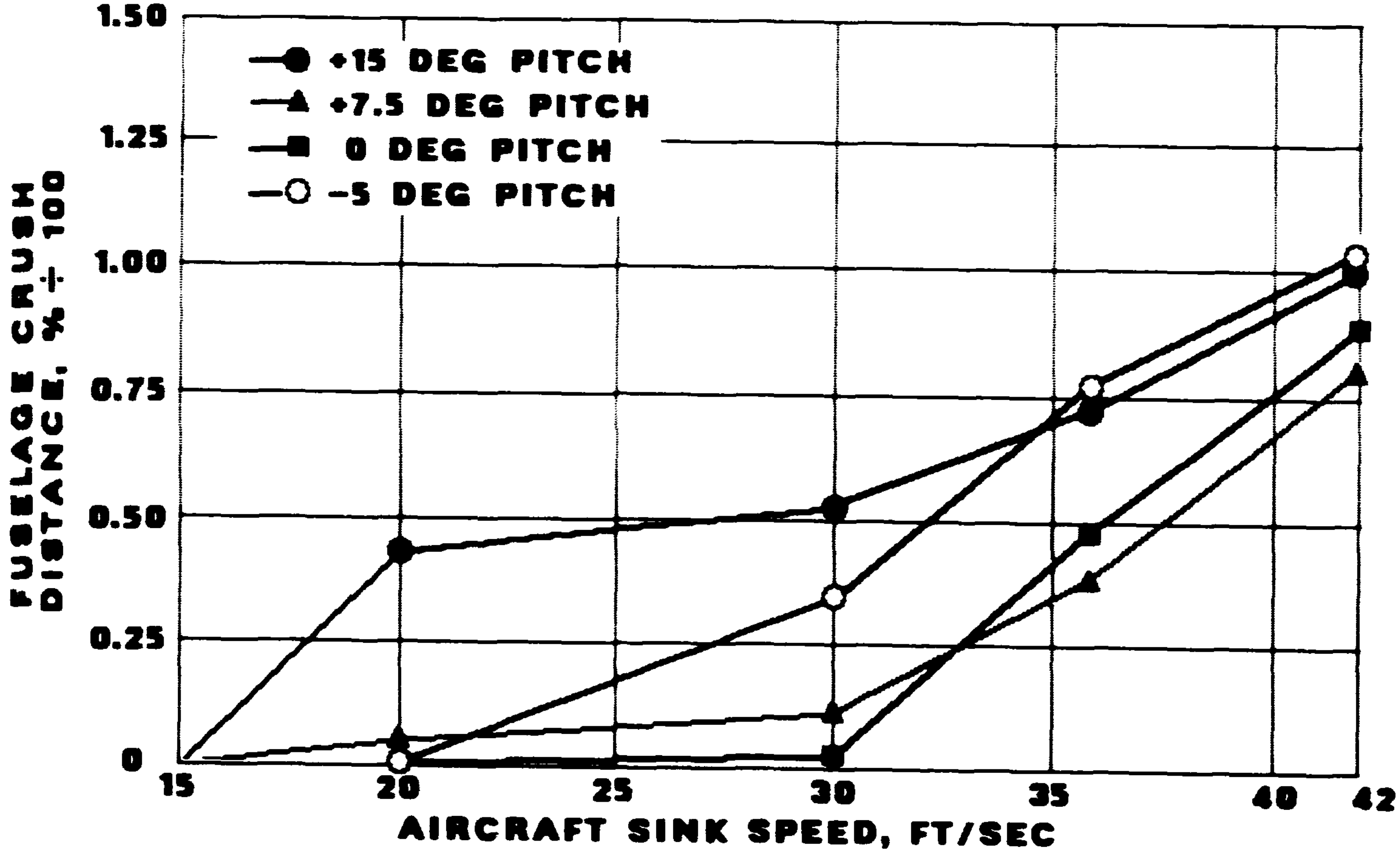

Figure A-1. Nose region; 0 degree roll, landing gear extended.

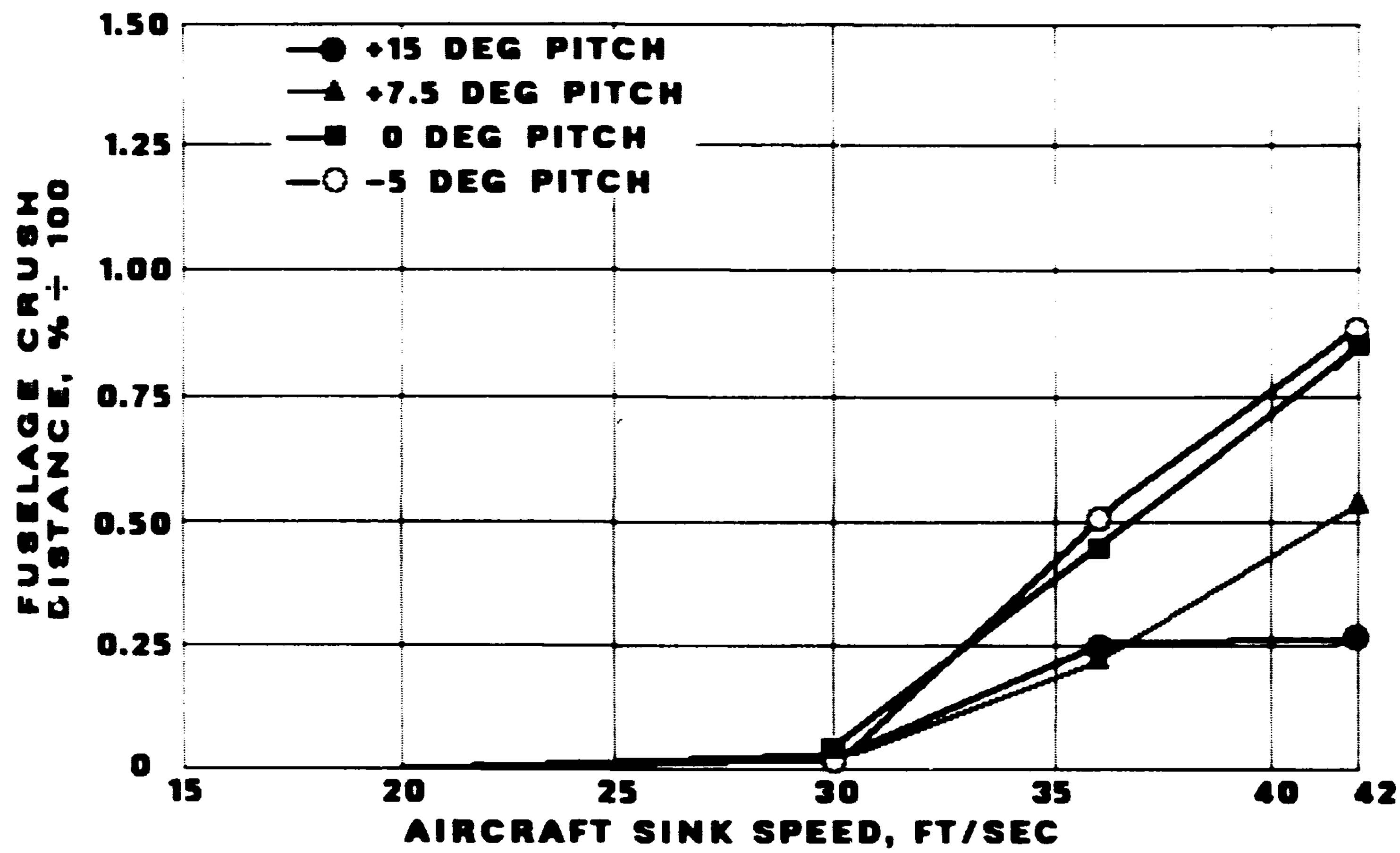

Figure A-2. Mid region; 0 degree roll, landing gear extended.

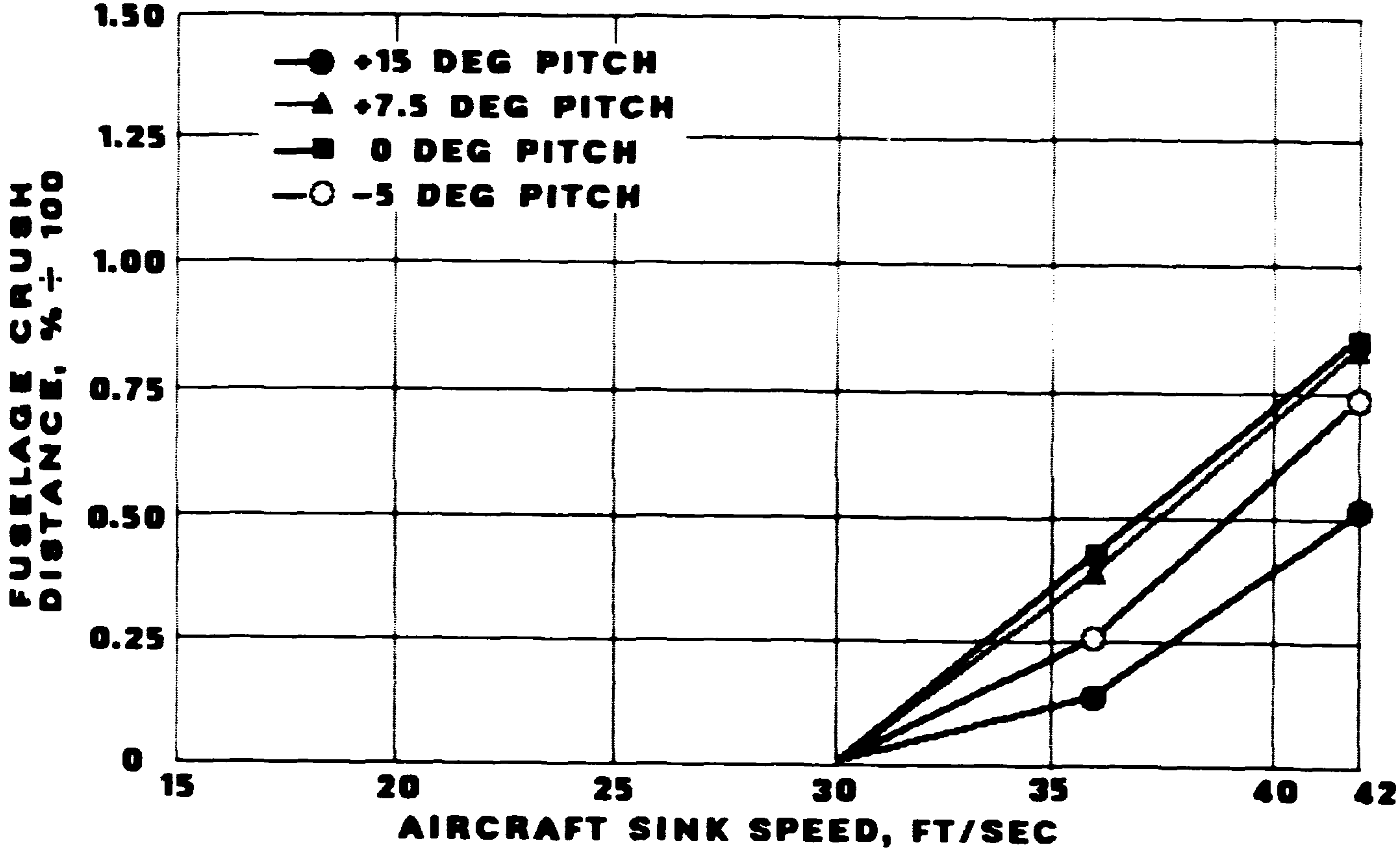

Figure A-3. Tail region; 0 degree roll, landing gear extended.

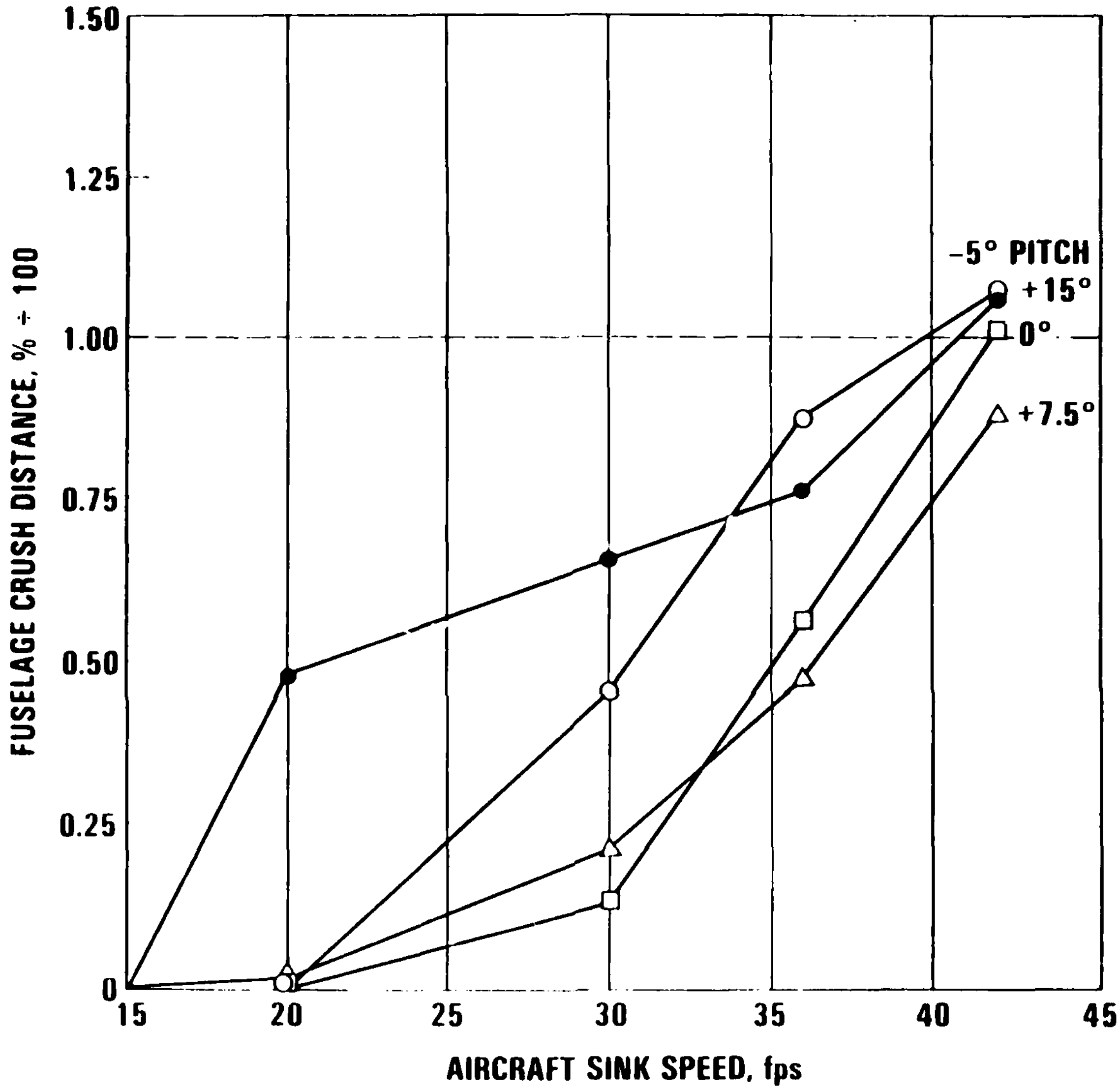

Figure A-4. Nose region; 5 degree roll, landing gear extended.

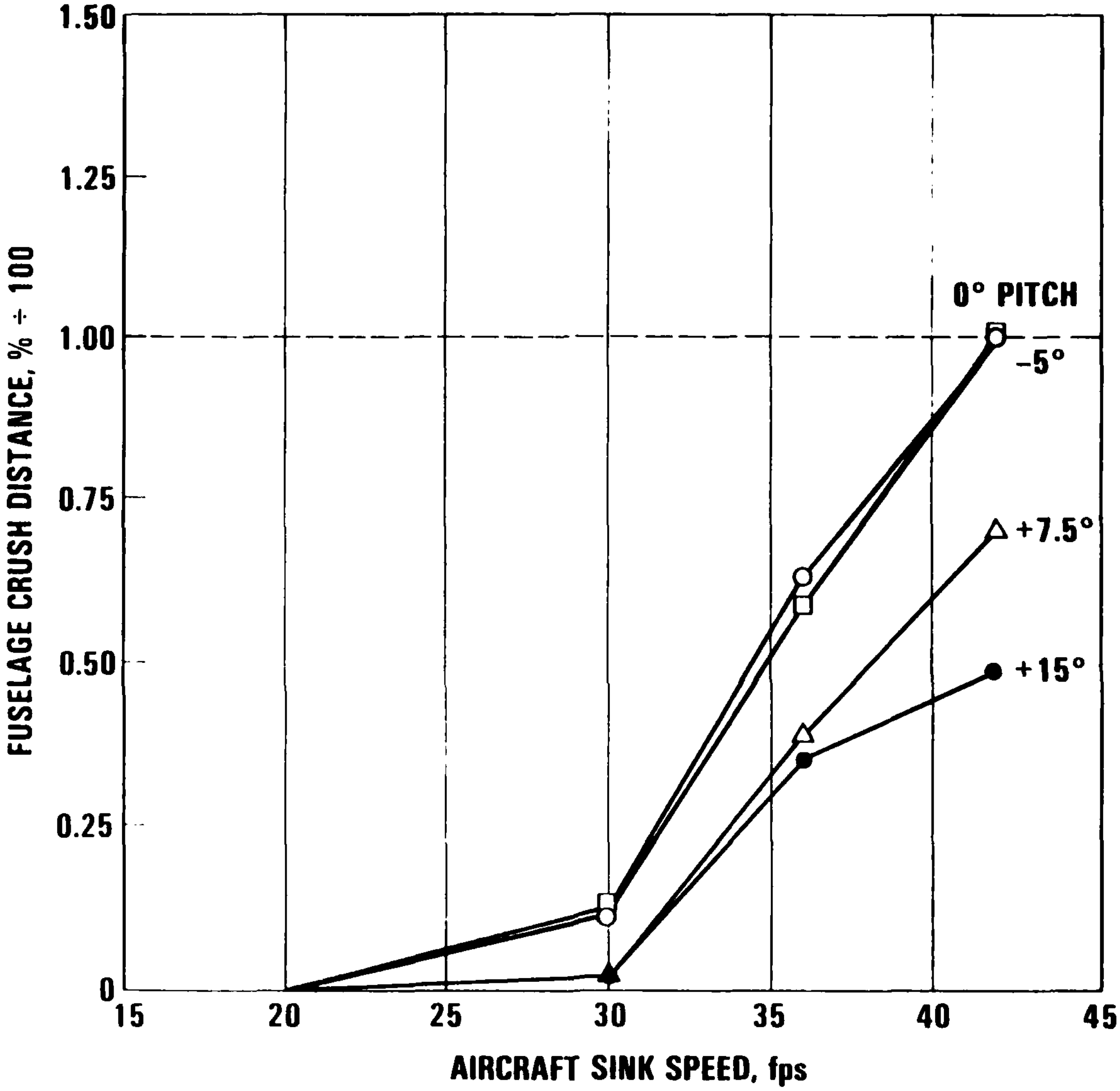

Figure A-5. Mid region; 5 degree roll, landing gear extended.

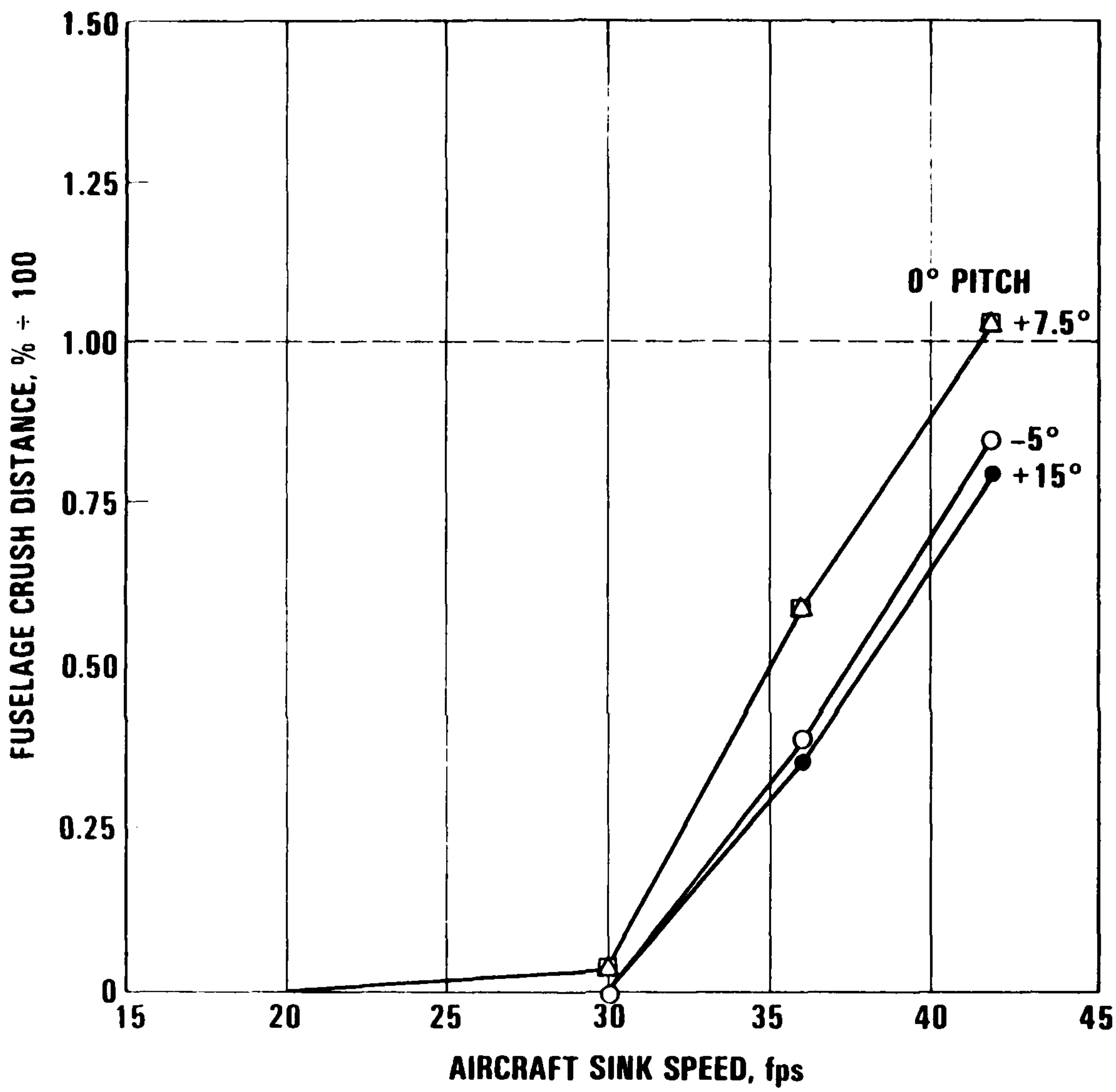

Figure A-6. Tail region; 5 degree roll, landing gear extended.

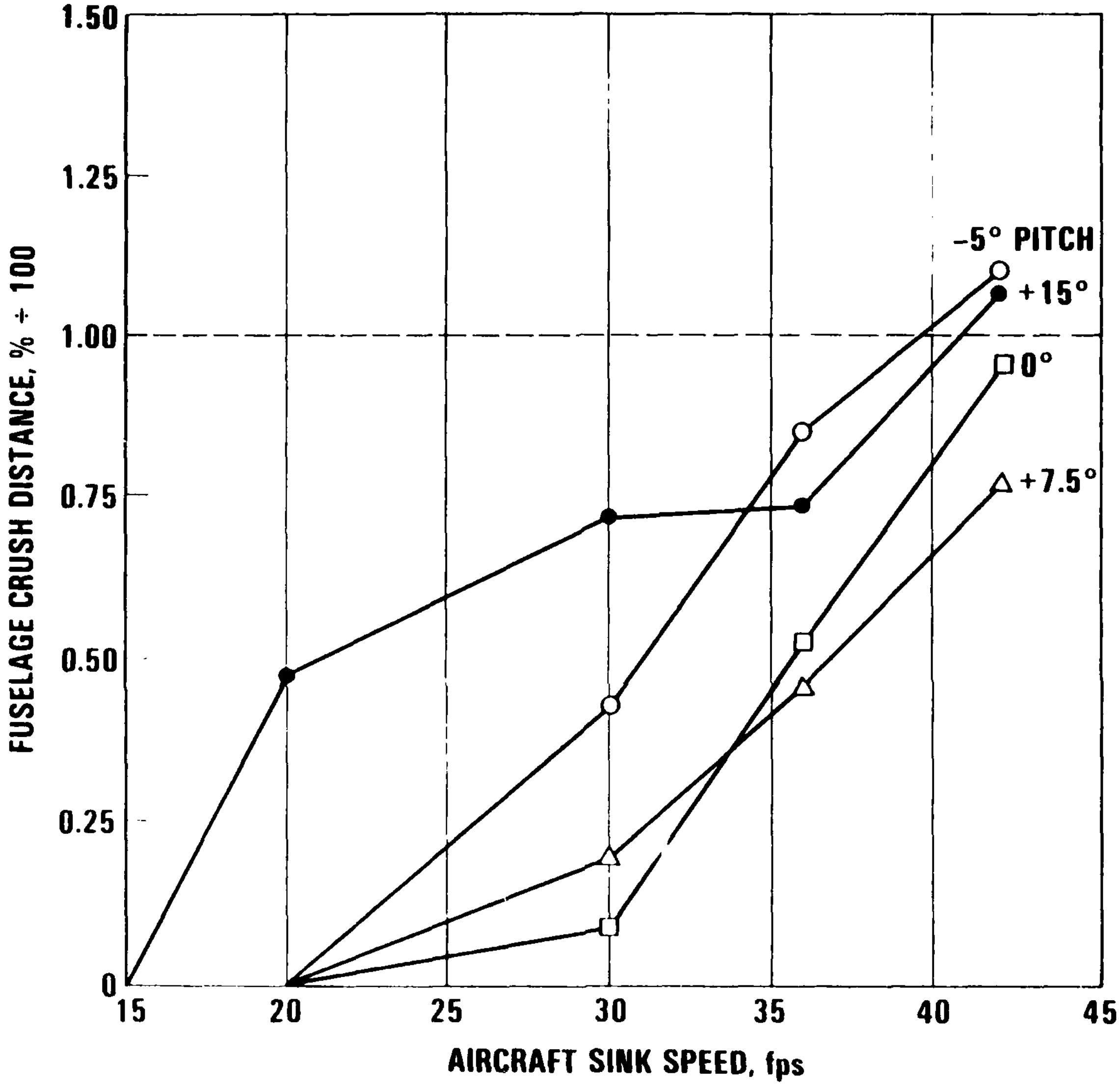

Figure A-7. Nose region; 10 degree roll, landing gear extended.

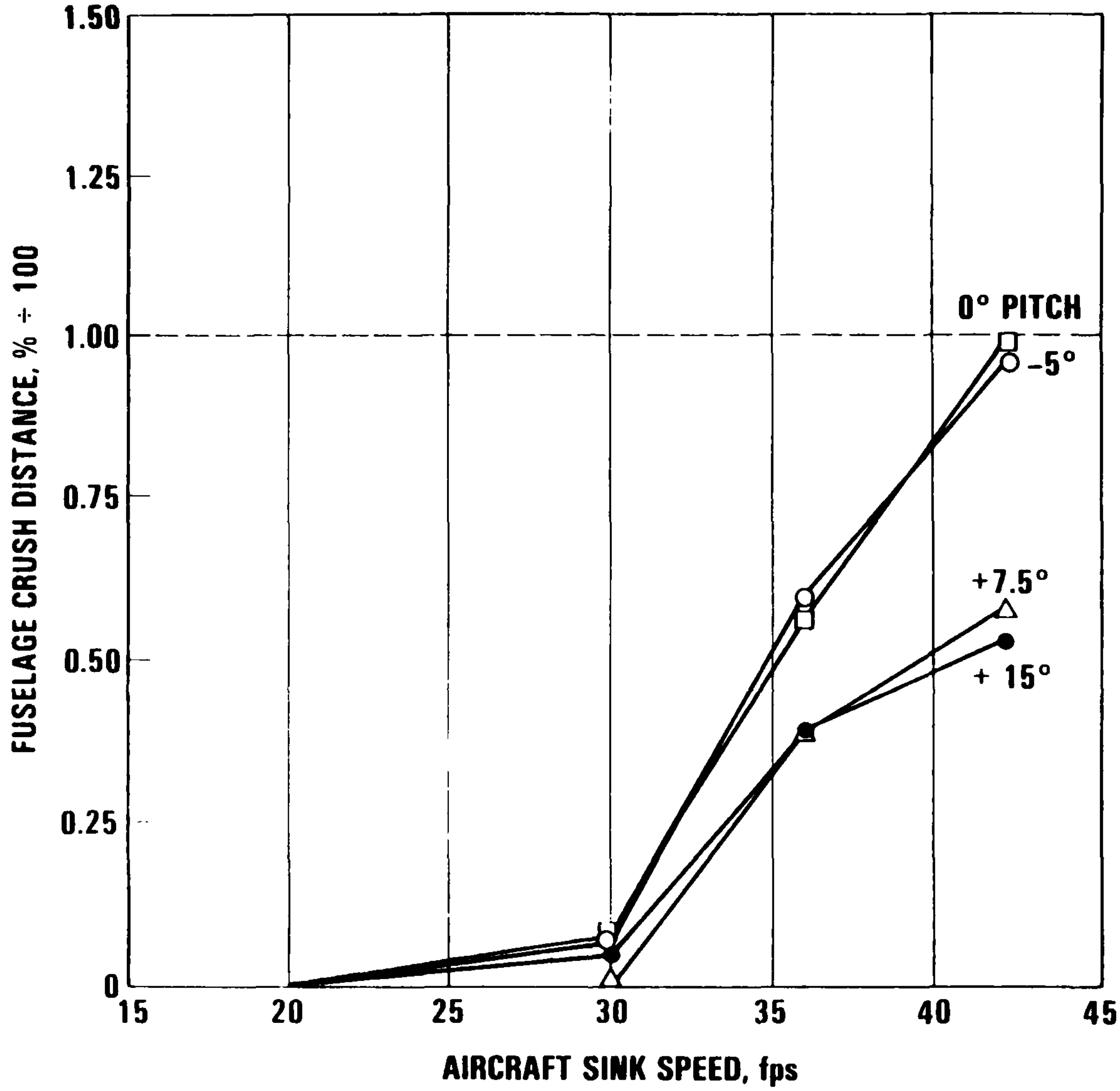

Figure A-8. Mid region; 10 degree roll, landing gear extended.

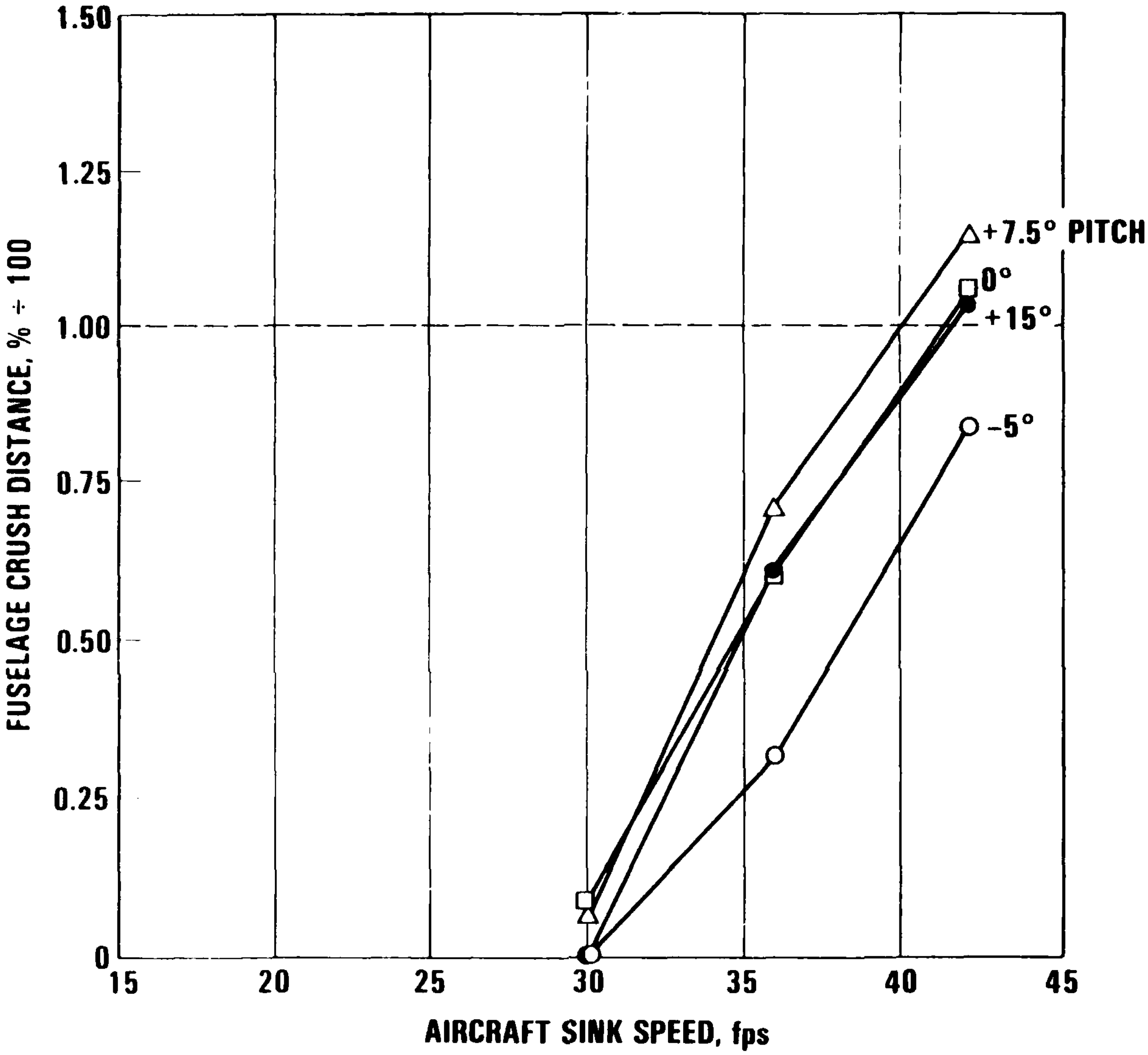

Figure A-9. Tail region; 10 degree roll, landing gear extended.

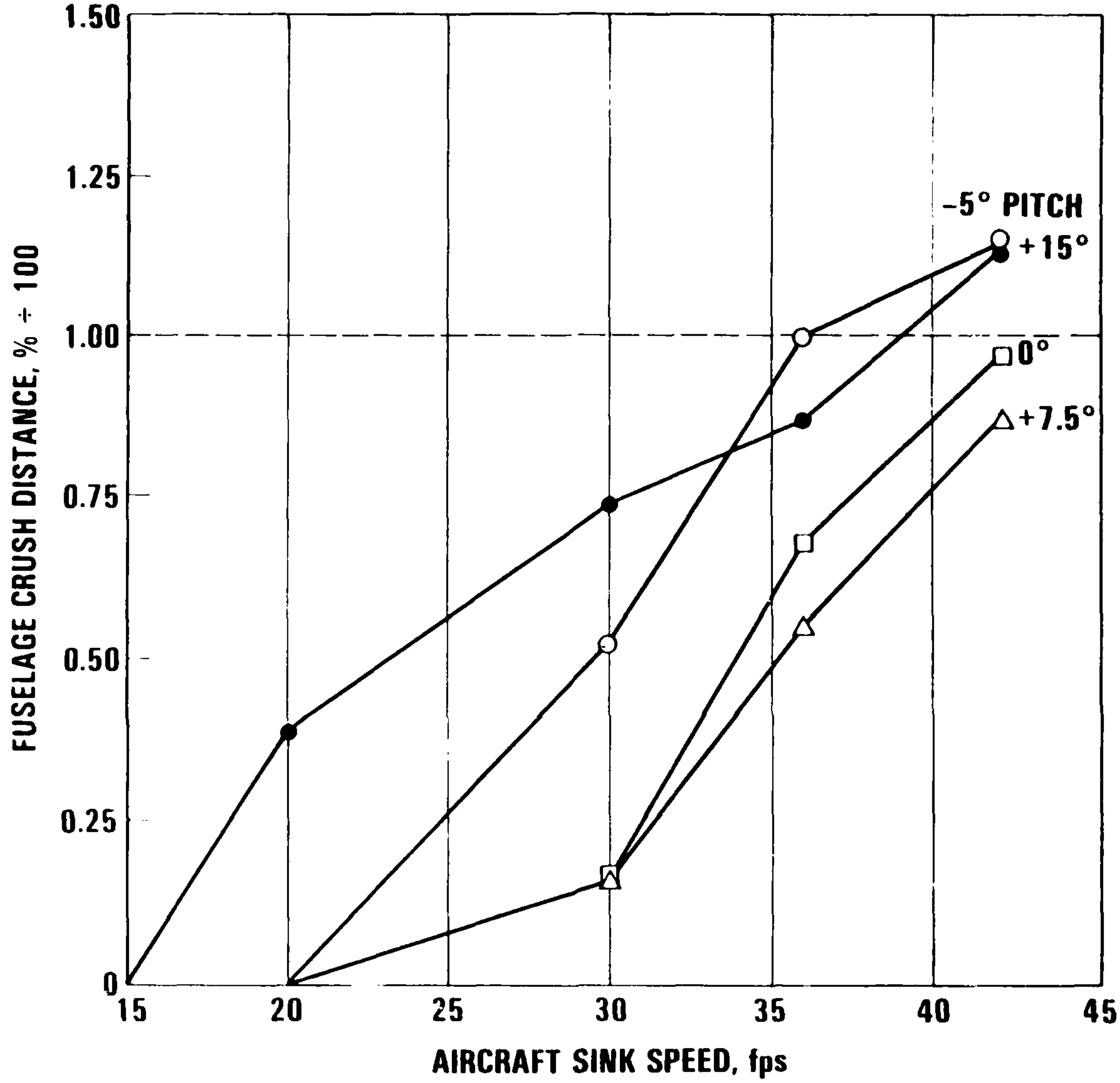

Figure A-10. Nose region; 15 degree roll, landing gear extended.

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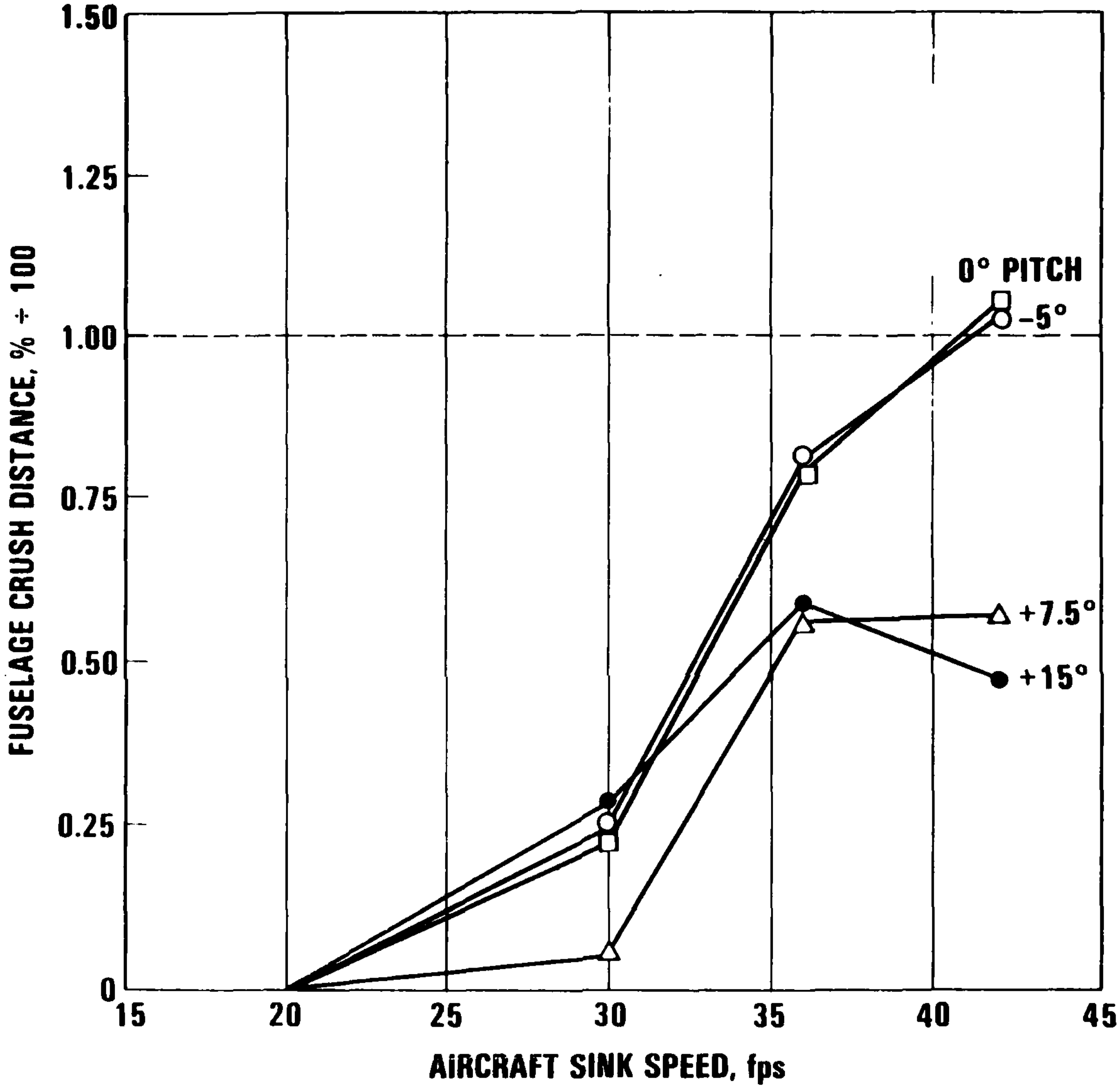

Figure A-11. Mid region; 15 degree roll, landing gear extended.

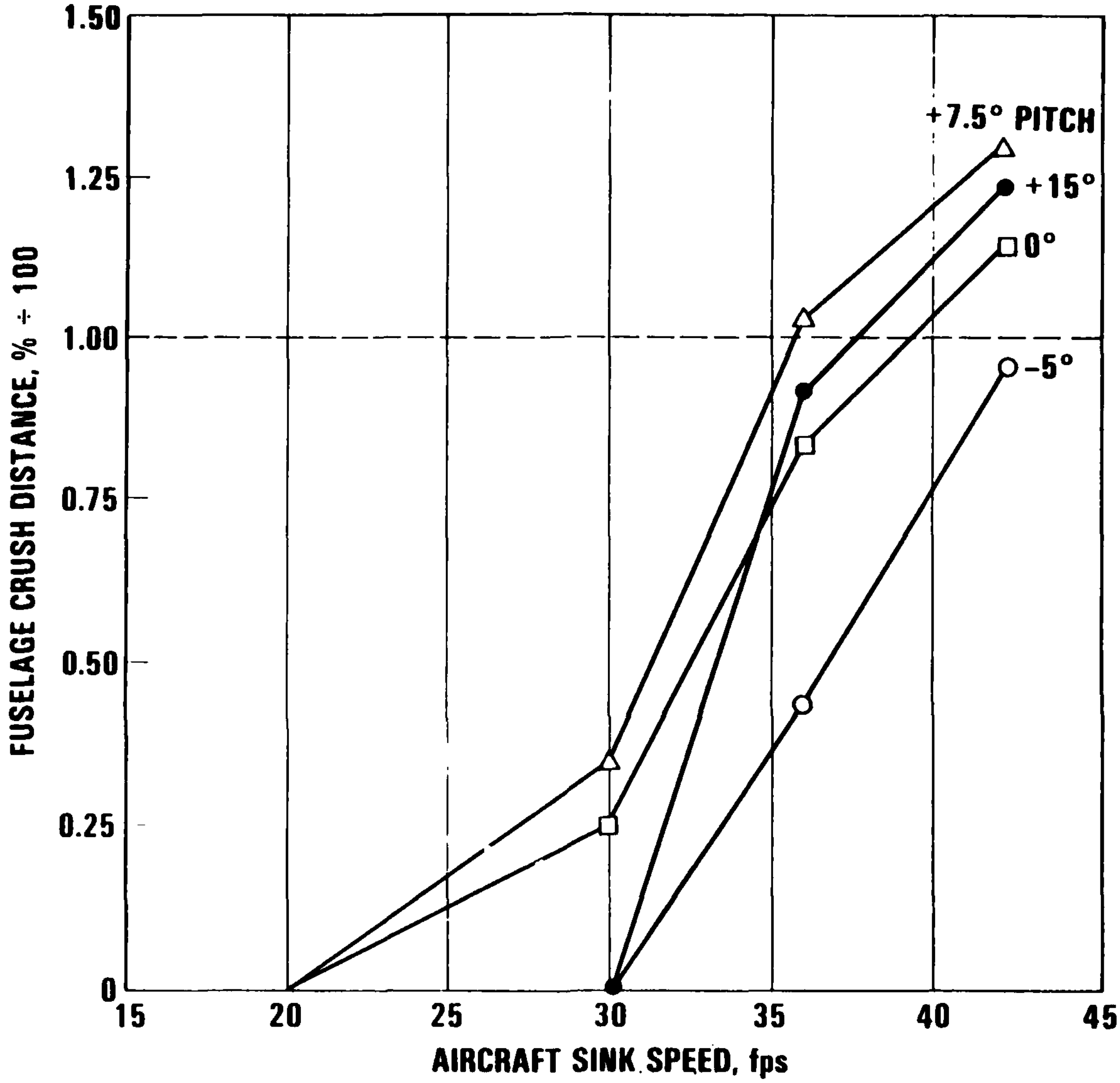

Figure A-12. Tail region; 15 degree roll, landing gear extended.

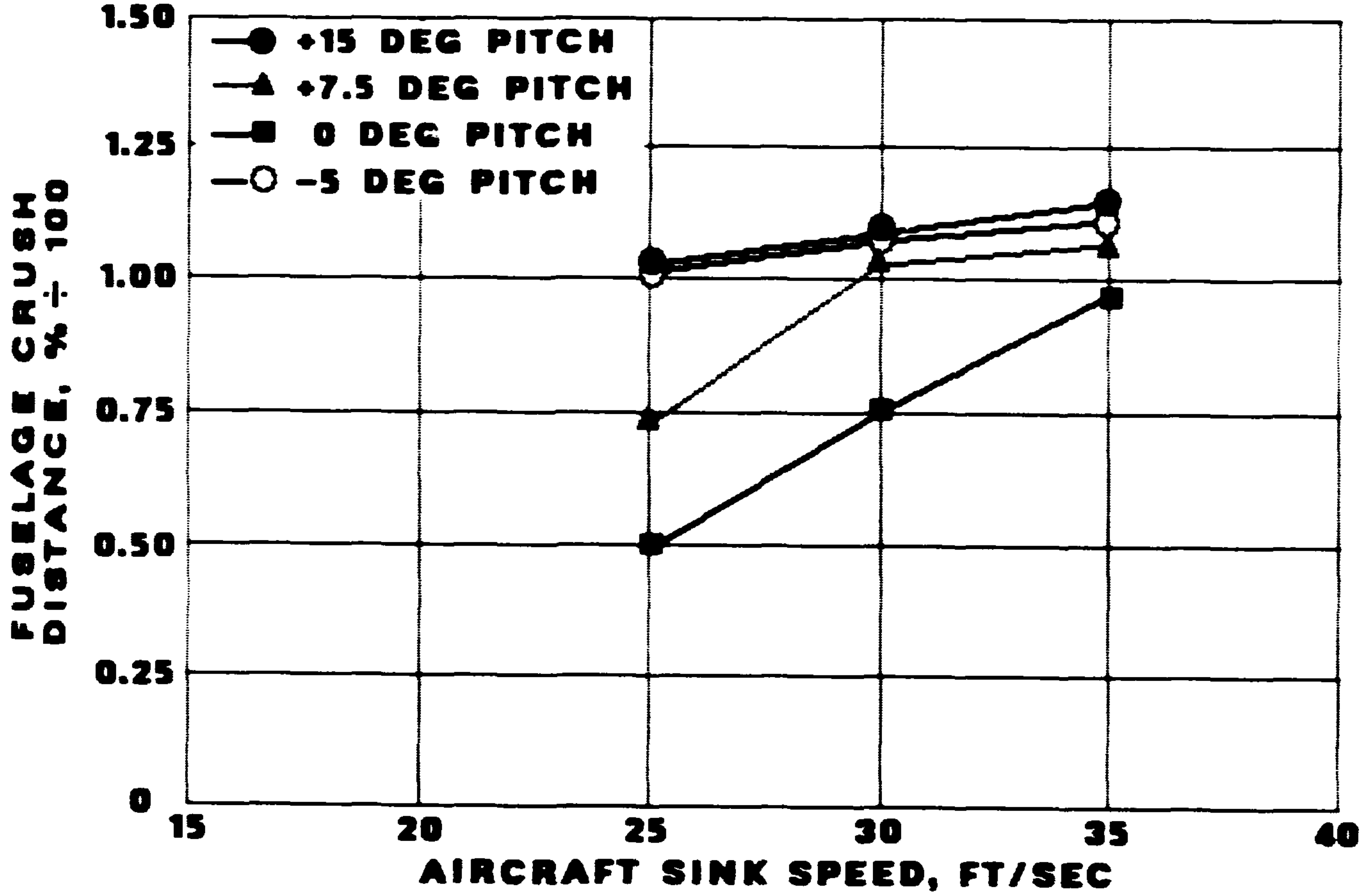

Figure A-13. Nose region; 0 degree roll, landing gear retracted.

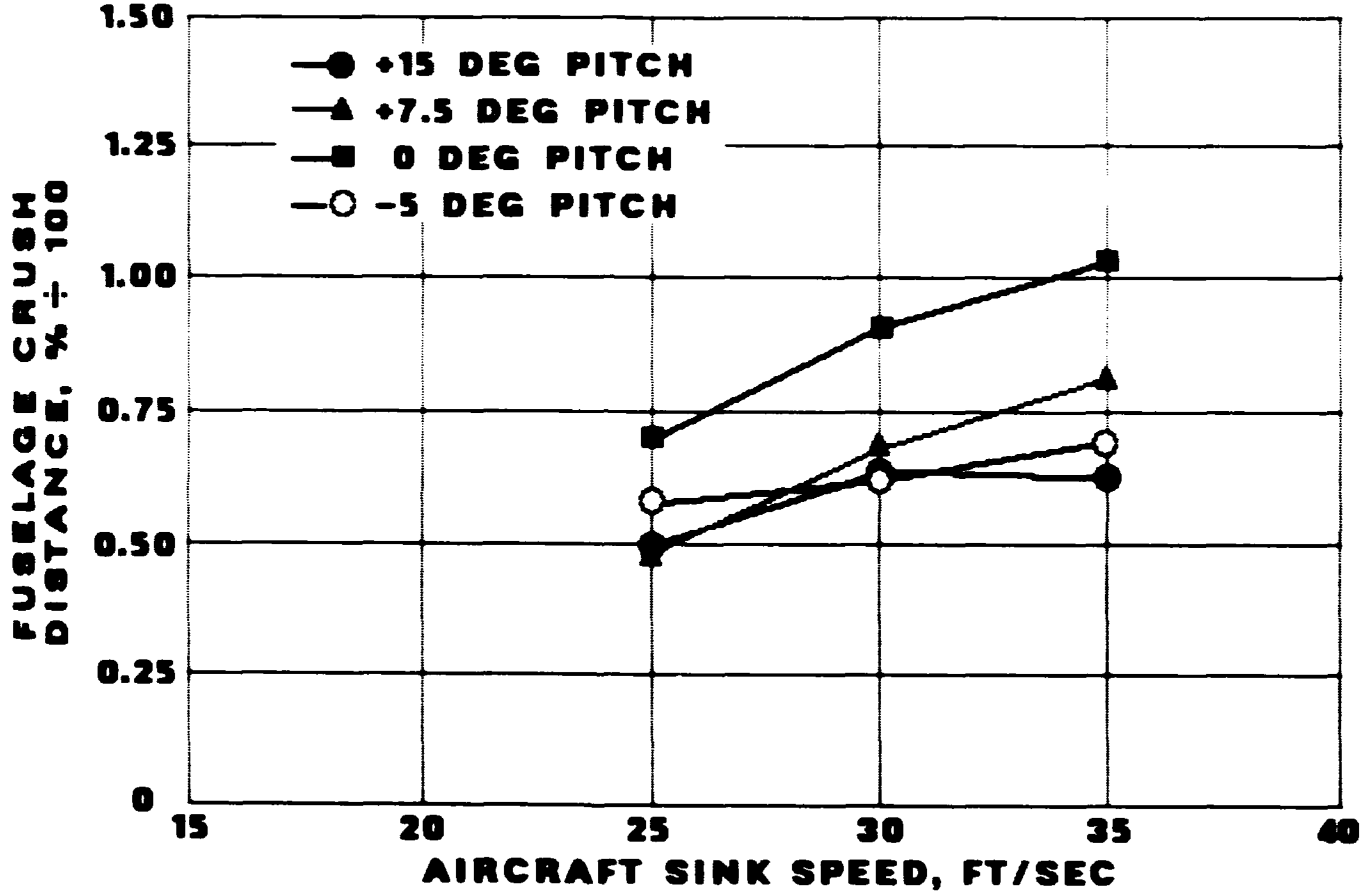

Figure A-14. Mid region; 0 degree roll, landing gear retracted.

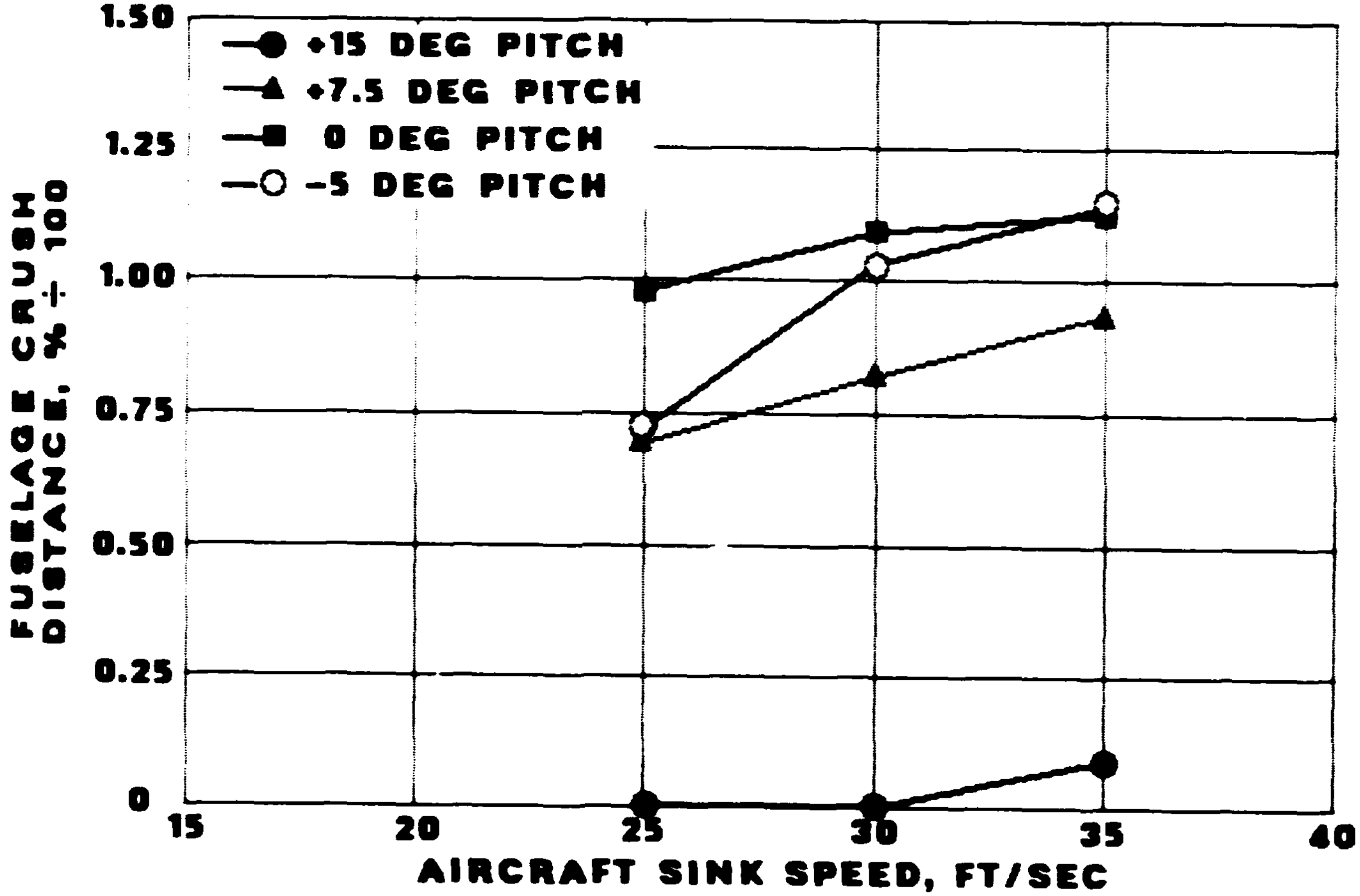

Figure A-15. Tail region; 0 degree roll, landing gear retracted.

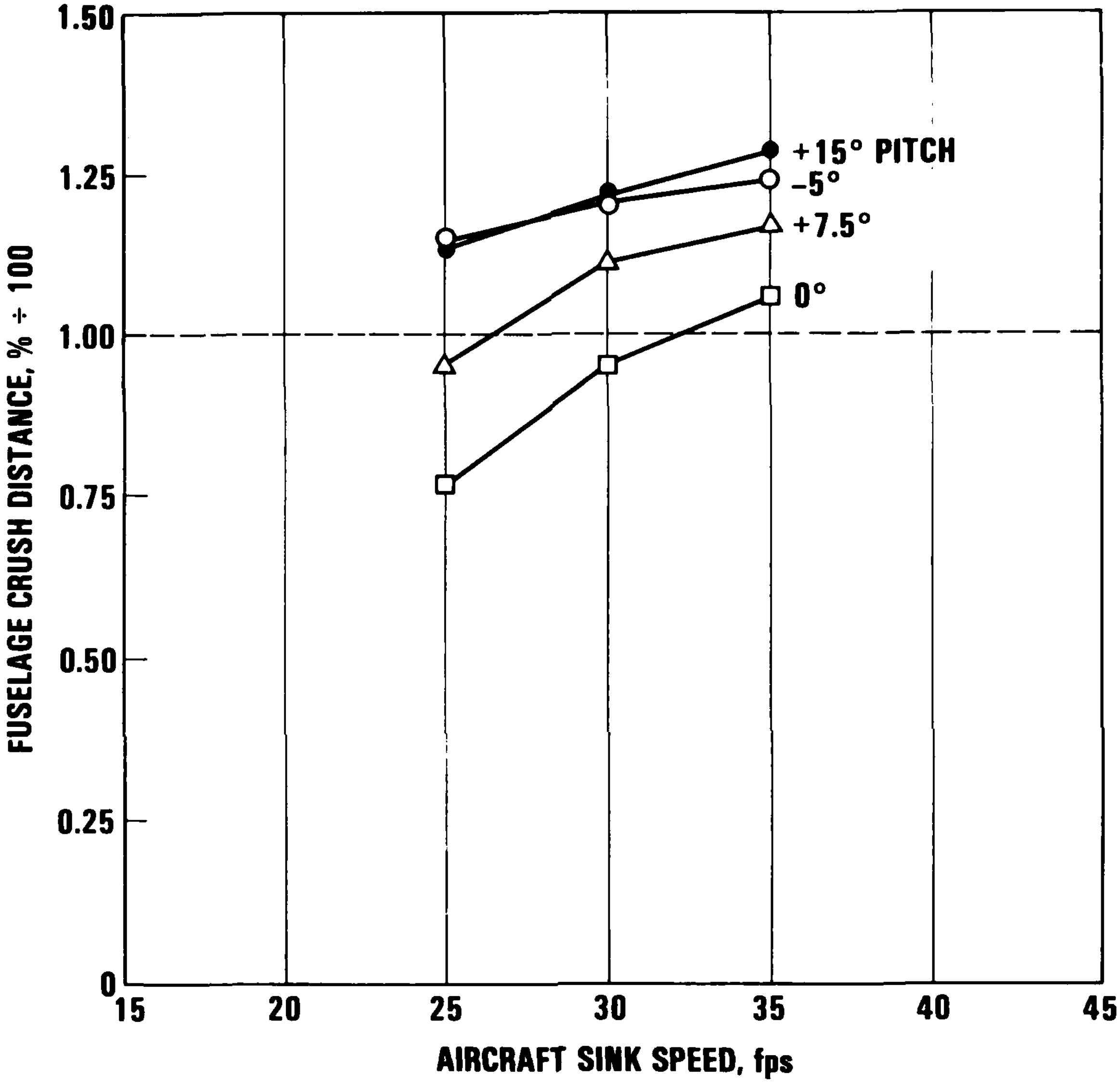

Figure A-16. Nose region; 5 degree roll, landing gear retracted.

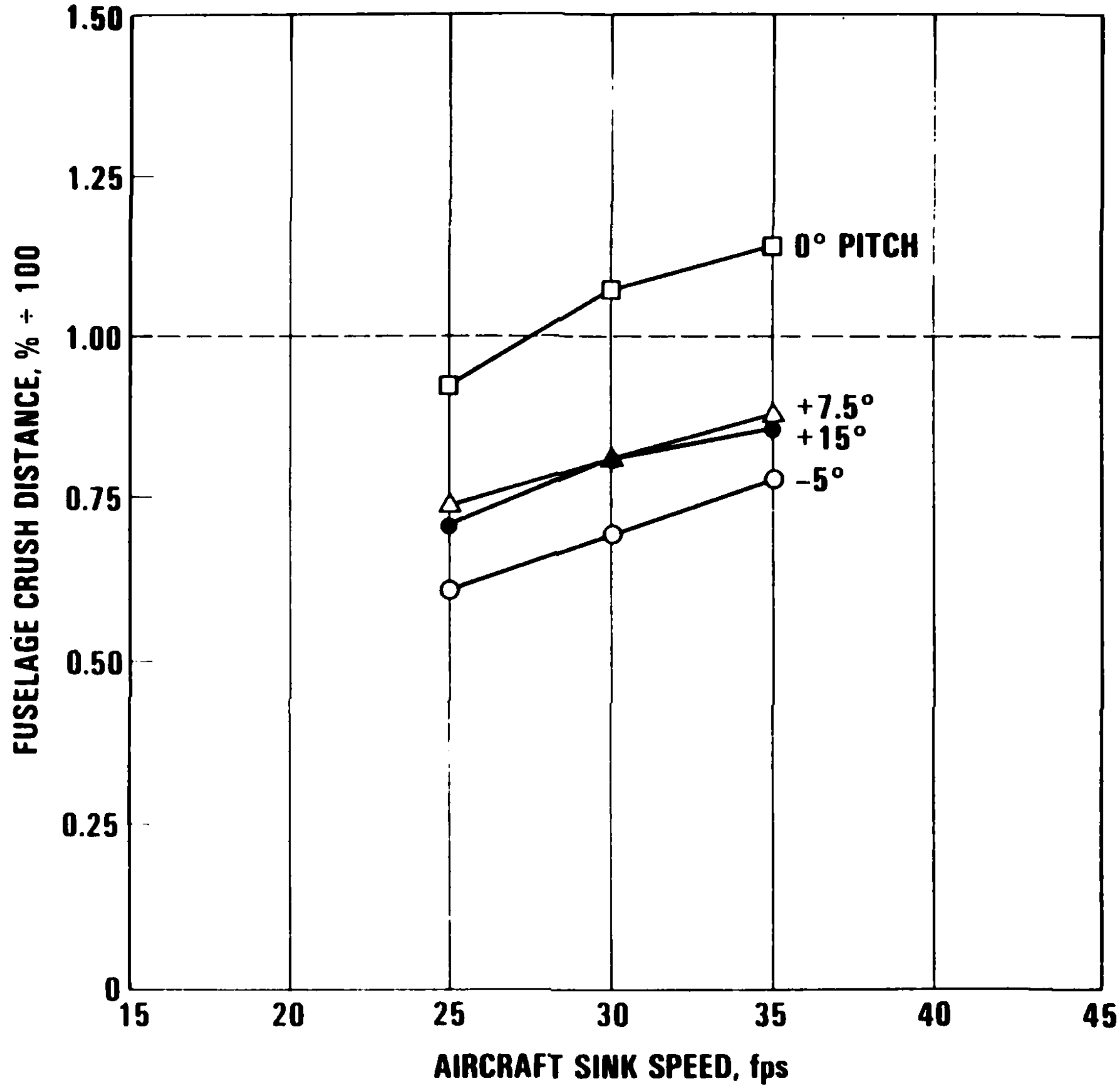

Figure A-17. Mid region; 5 degree roll, landing gear retracted.

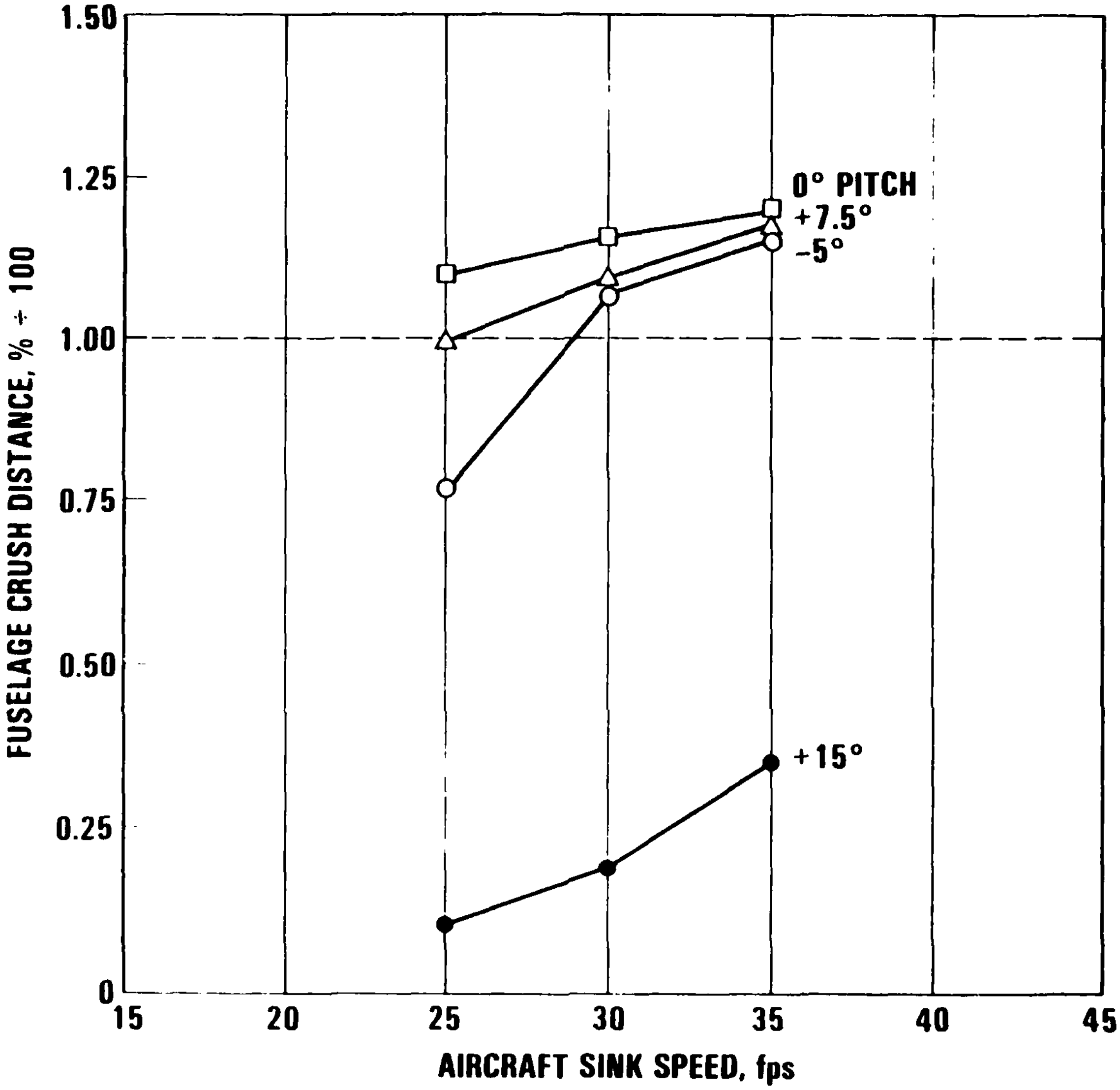

Figure A-18. Tail region; 5 degree roll, landing gear retracted.

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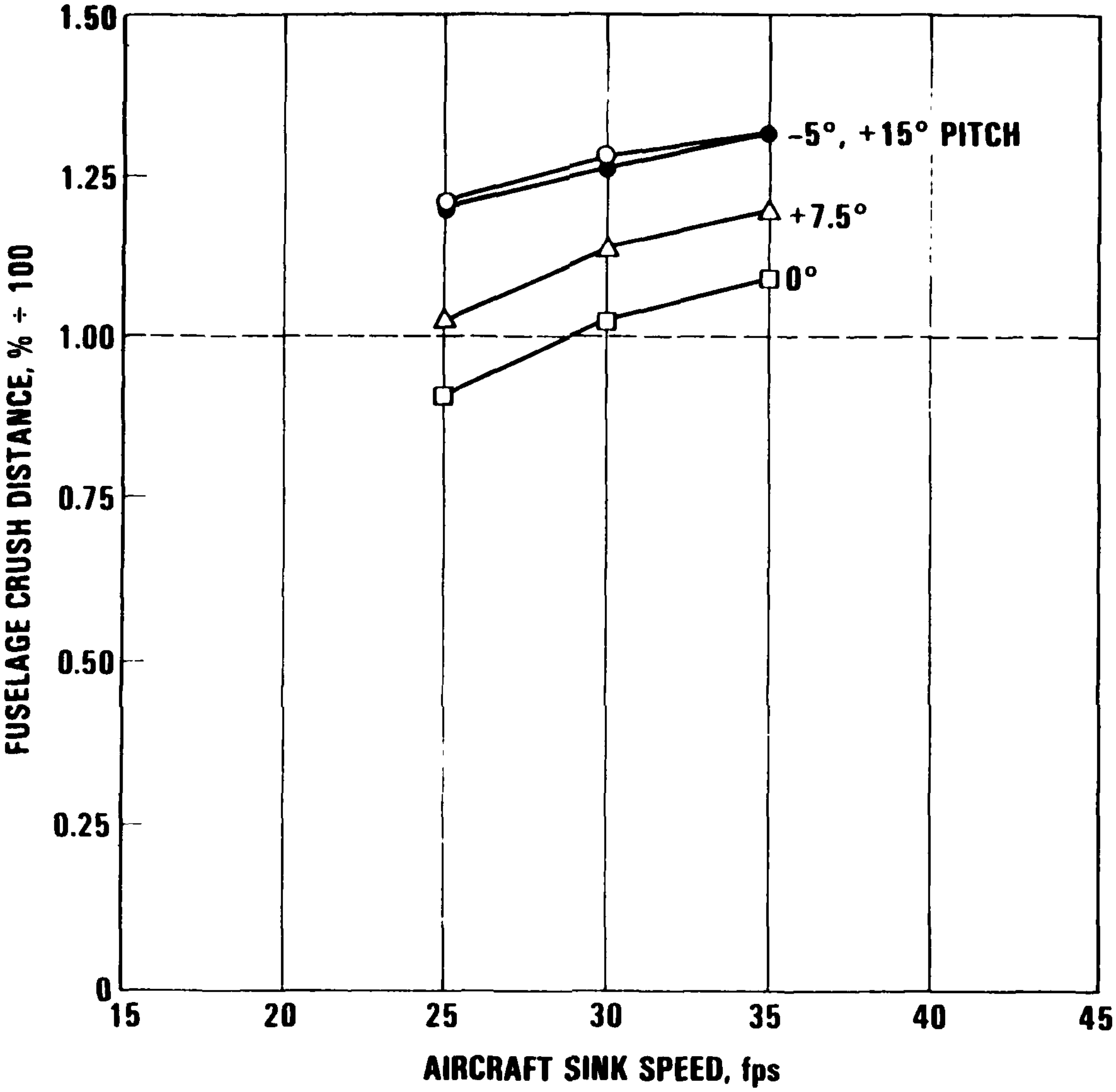

Figure A-19. Nose region; 10 degree roll, landing gear retracted.

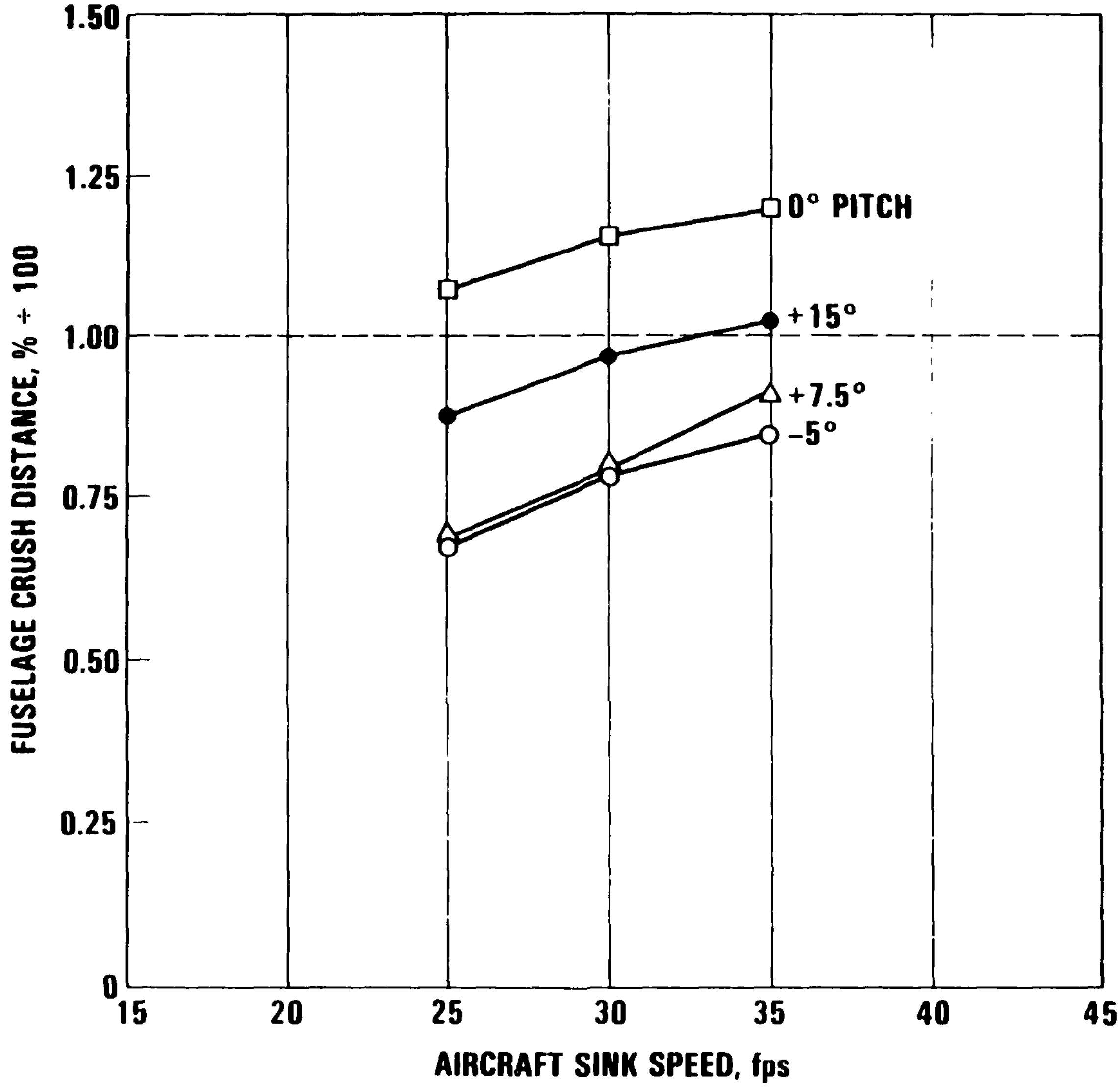

Figure A-20. Mid region; 10 degree roll, landing gear retracted.

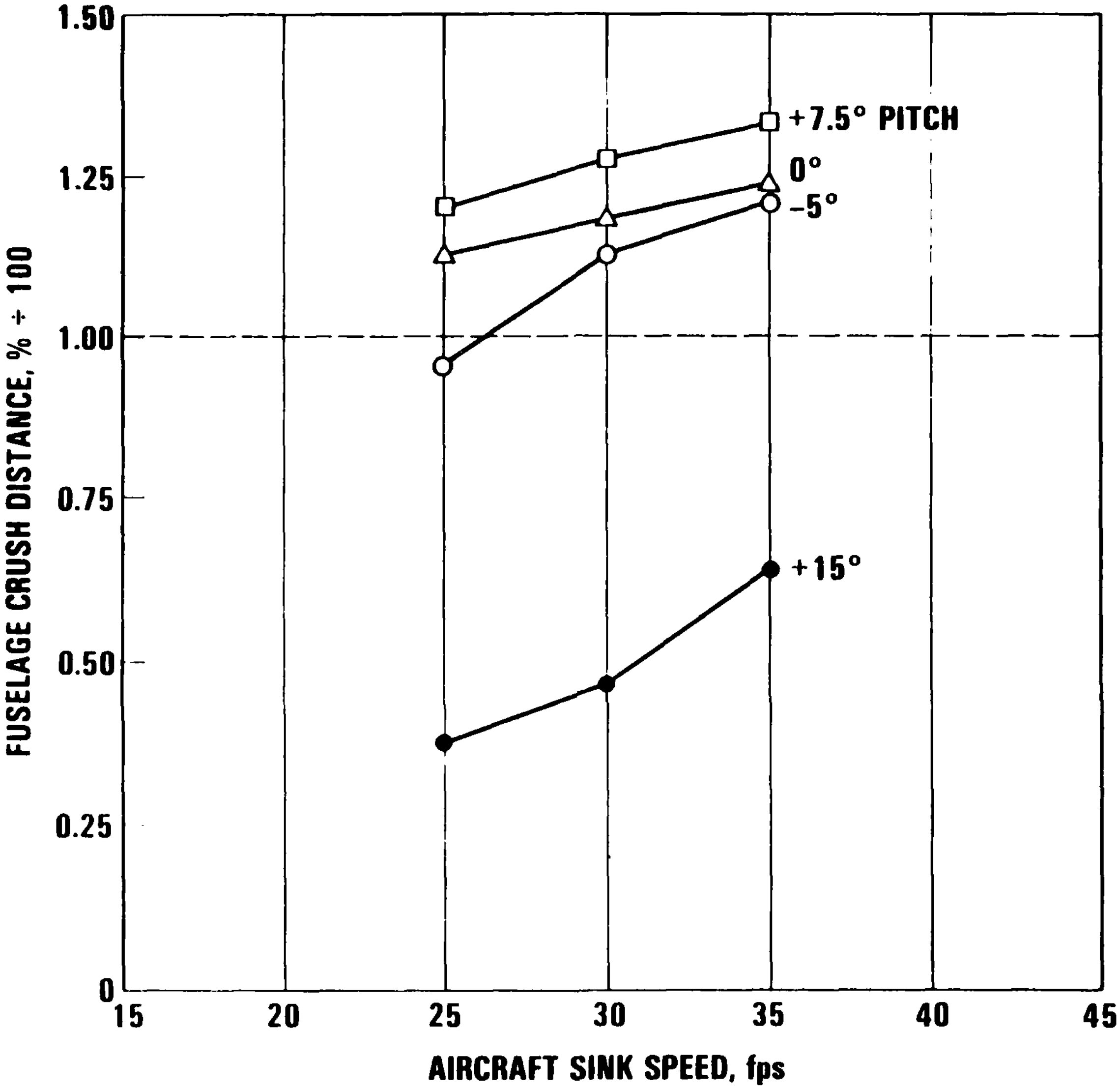

Figure A-21. Tail region; 10 degree roll, landing gear retracted.

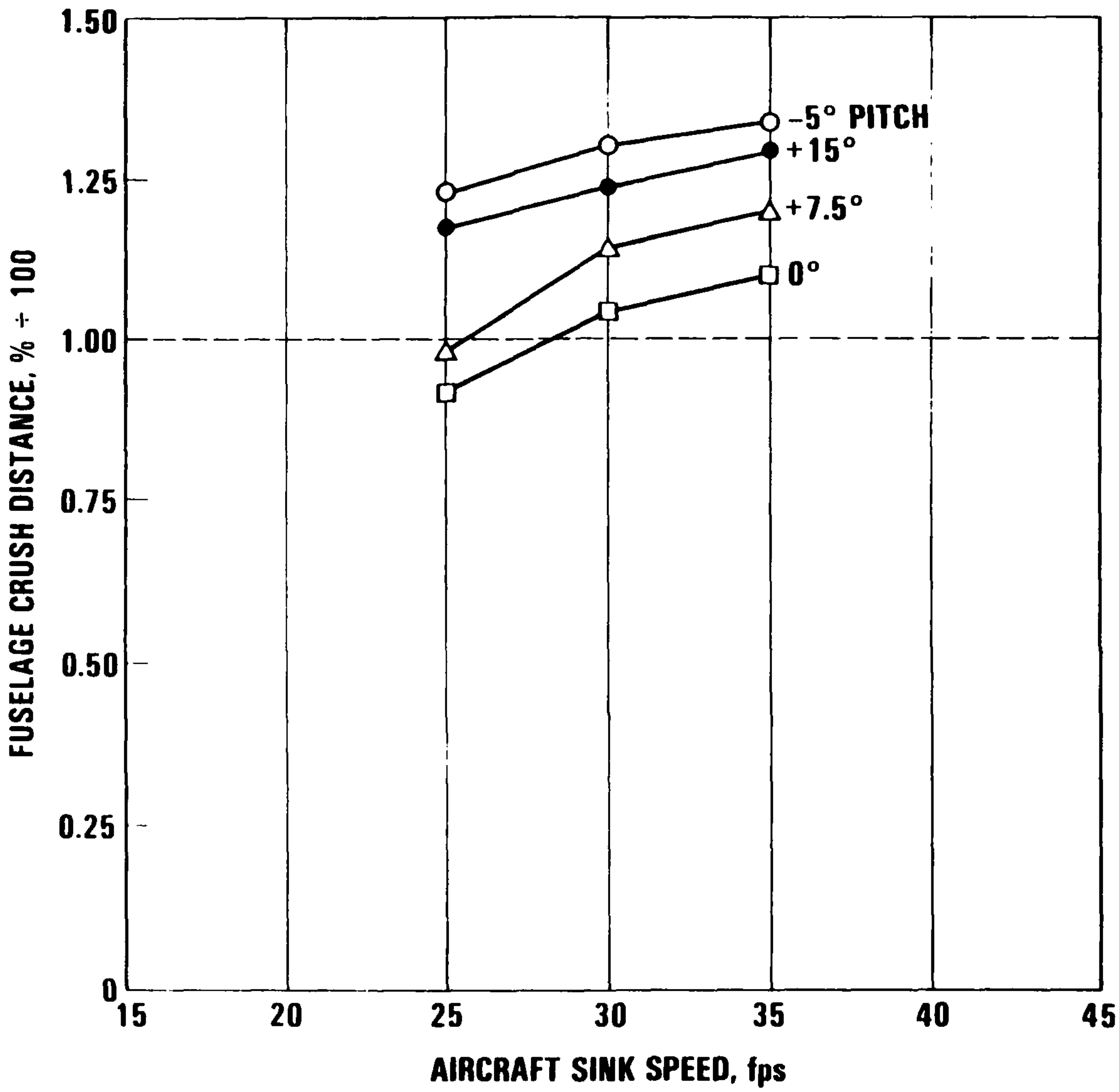

Figure A-22. Nose region; 15 degree roll, landing gear retracted.

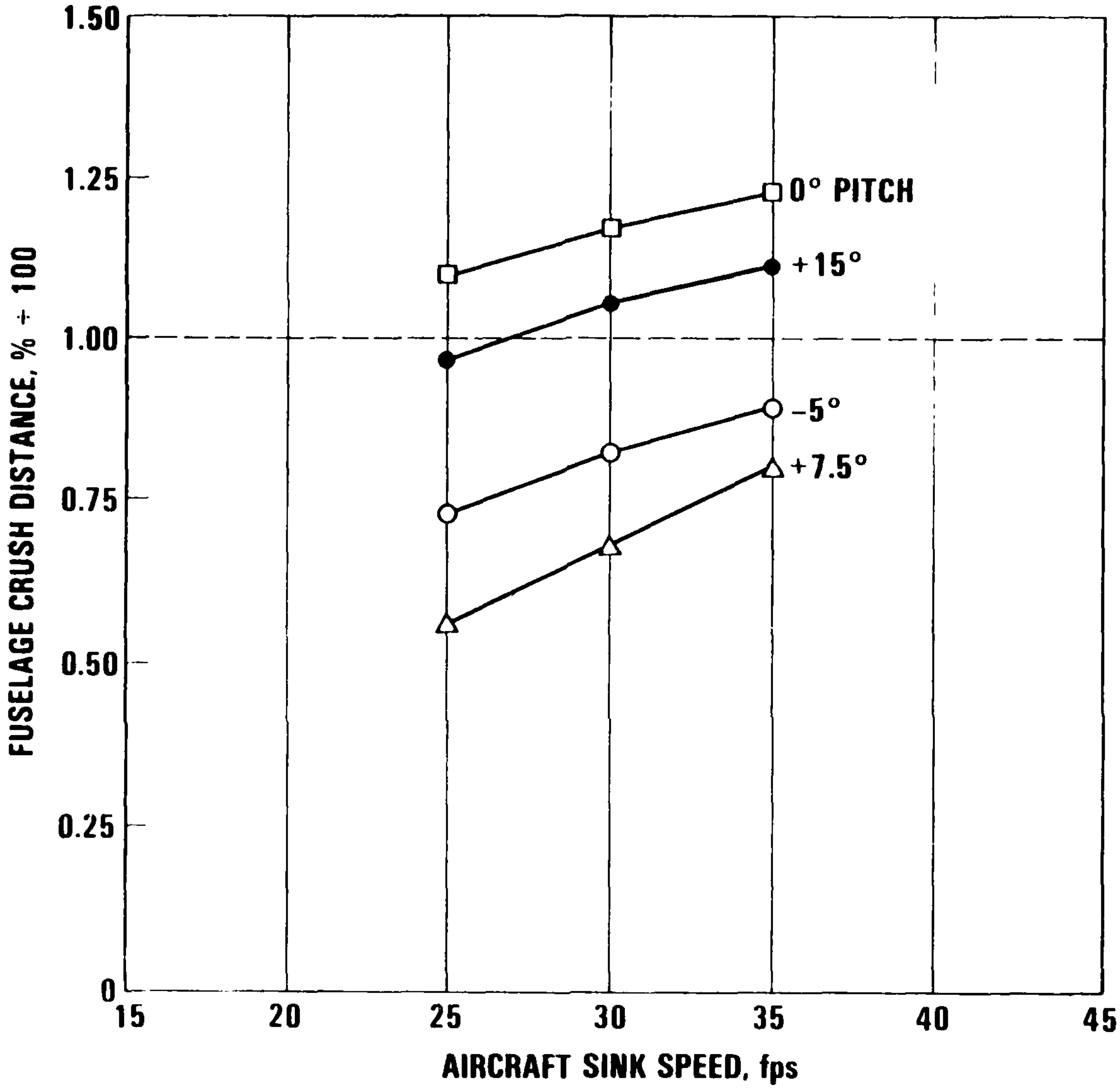

Figure A-23. Mid region; 15 degree roll, landing gear retracted.

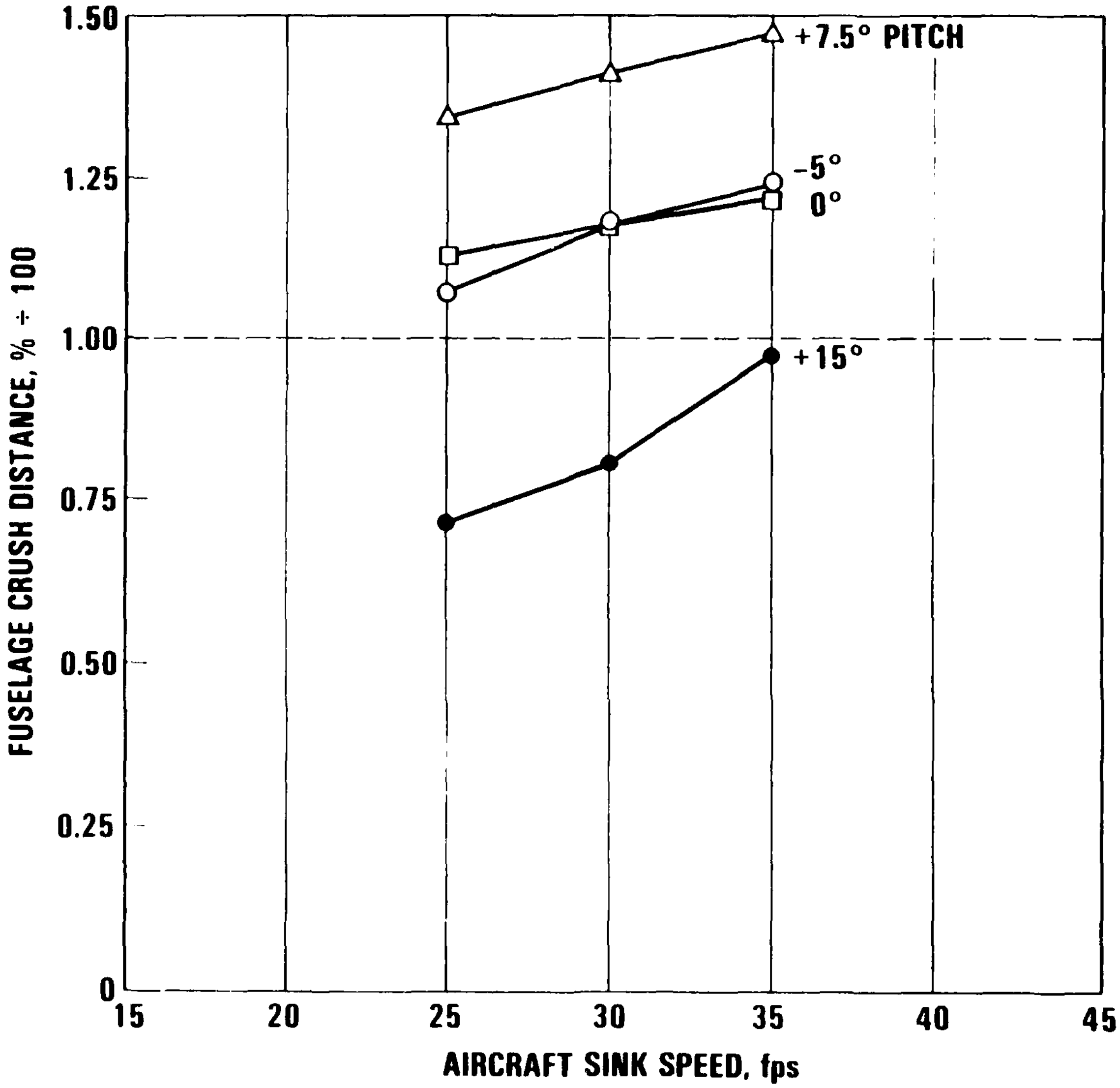

Figure A-24. Tail region; 15 degree roll, landing gear retracted.

APPENDIX B

DETAIL DATA ON FUSELAGE DEFORMATIONS FROM PHASE II STUDY OF COUPLED LANDING GEAR

TABLE B-1. FUSELAGE CRUSH DISTANCE FOR 42 fps IMPACT, LANDING GEAR EXTENDED

AIRCRAFT IMPACT ATTITUDE, DEG.		SPRING/MASS LOCATION DEFLECTIONS, IN.																				
ROLL	PITCH	1	7	8	8′	12	12′	15	15′	16	16′	18″	24	30	31	31′	35	35′	38	38′	39	39′
0	-5	6.71	6.71	7.23	7.21	6.34	6.33	5.44	5.43	5.28	5.28	0.05	1	7	8	8′	12	12′	15	15′	16	16′
0	0	6.21	6.20	6.30	6.29	6.13	6.12	6.11	6.10	6.19	6.19	1.45										
0	7.5	4.42	4.43	5.63	5.62	3.78	3.77	3.49	3.48	5.92	5.92	5.48										
0	15	3.87	3.87	7.21	7.20	1.80	1.79	0.07	0.07	3.96	3.98	5.62										
5	-5	6.82	7.39	7.82	7.33	7.02	6.43	6.22	5.81	6.09	5.87	0.72	5.71	5.16	5.89	6.33	4.82	5.35	4.70	5.06	4.98	5.18
5	0	6.66	7.26	7.15	6.70	7.23	6.64	7.32	6.71	7.26	6.86	1.55	5.57	5.02	5.19	5.62	4.97	5.52	4.97	5.56	5.32	5.68
5	7.5	5.02	5.65	6.49	6.04	5.05	4.43	5.20	4.40	7.34	6.80	5.40	3.80	3.22	4.48	4.91	2.59	3.20	2.04	2.81	4.63	5.15
5	15	5.01	5.62	7.67	7.17	4.14	3.52	2.42	1.46	5.68	4.98	5.69	3.84	3.32	5.97	6.34	1.70	2.30	0	0	2.09	2.77
10	-5	6.46	6.72	7.87	7.09	6.84	6.08	6.15	5.74	5.99	5.82	0.67	5.10	4.53	5.10	5.63	4.56	4.91	4.92	5.15	5.20	5.32
10	0	6.32	6.94	6.76	6.36	7.02	6.34	7.46	6.64	7.52	6.98	1.66	5.33	4.92	5.26	5.56	4.77	5.22	4.64	5.25	4.98	5.45
10	7.5	4.19	4.62	5.58	5.39	4.21	3.64	5.92	4.46	8.26	7.22	5.17	3.52	3.32	4.95	5.02	2.38	2.70	1.36	2.20	3.19	4.11
10	15	4.64	5.30	7.59	7.12	3.84	3.05	3.99	1.87	7.53	5.97	5.91	3.51	3.08	6.10	6.37	1.18	1.72	0	0	0	1.07
15	-5	5.98	7.82	8.14	6.61	7.31	5.57	6.76	5.78	6.76	6.25	1.34	2.83	2.00	1.92	3.19	2.43	3.16	3.79	4.30	4.66	4.94
15	0	5.72	7.18	6.88	6.10	7.38	5.73	8.21	6.30	8.16	6.93	1.06	3.86	3.26	4.28	4.69	2.70	3.41	1.62	3.02	2.26	3.35
15	7.5	3.66	4.66	6.20	5.69	4.08	2.68	7.05	4.14	9.31	7.37	4.67	2.25	1.81	4.43	4.72	0.22	0.79	0	0	0	1.47
15	15	3.13	5.29	8.04	6.49	3.38	0.97	5.00	0.93	8.81	6.13	5.82	0	0	2.92	3.12	0	0	0	0	0	0

REMARK: ○ INDICATES THAT THESE DEFLECTIONS ARE THE SAME DEFLECTIONS AS THE SPRING THAT APPEARS IN THE CIRCLE

TABLE B-2. FUSELAGE CRUSH DISTANCE FOR 36 fps IMPACT, LANDING GEAR EXTENDED

AIRCRAFT IMPACT ATTITUDE, DEG.		SPRING/MASS LOCATION DEFLECTIONS, IN.																				
ROLL	PITCH	1	7	8	8′	12	12′	15	15′	16	16′	18″	24	30	31	31′	35	35′	38	38′	39	39′
0	-5	4.27	4.26	5.40	5.39	3.52	3.53	2.22	2.22	1.81	1.80	0	1	7	8	8′	12	12′	15	15′	16	16′
0	0	3.24	3.24	3.36	3.35	3.17	3.16	3.06	3.05	3.10	3.09	0										
0	7.5	1.95	1.96	2.79	2.78	1.56	1.56	1.32	1.32	2.77	2.77	1.57										
0	15	2.96	2.96	5.25	5.24	1.79	1.78	0	0	0.95	0.94	0.46										
5	-5	4.74	5.28	6.35	5.87	4.52	4.00	3.23	2.78	2.65	2.37	0	3.64	3.14	4.31	4.75	2.53	3.02	1.45	1.89	1.22	1.47
5	0	3.66	4.17	4.15	3.75	4.16	3.64	4.15	3.64	4.06	3.72	0	2.69	2.22	2.39	2.78	2.17	2.64	2.10	2.61	2.33	2.66
5	7.5	2.54	3.02	3.56	3.18	2.81	2.30	2.89	2.27	4.09	3.61	1.40	1.61	1.16	1.98	2.31	0.75	1.25	0.52	1.07	1.64	2.10
5	15	3.27	3.70	5.49	5.20	2.61	2.11	0.87	0.13	2.53	1.86	0.28	2.52	2.18	4.41	4.60	0.85	1.23	0	0	0	0
10	-5	4.42	5.07	6.17	5.60	4.34	3.79	2.97	2.63	2.40	2.25	0	3.40	3.00	3.84	4.23	2.63	2.94	2.02	2.16	1.83	1.89
10	0	3.54	4.13	3.92	3.55	4.18	3.59	4.44	3.74	4.37	3.90	0	2.69	2.35	2.51	2.78	2.28	2.62	2.08	2.57	2.26	2.61
10	7.5	2.47	3.07	3.42	3.04	2.86	2.22	3.83	2.73	5.27	4.35	1.33	1.50	1.08	2.04	2.26	0.61	1.06	0.05	0.89	1.04	1.75
10	15	2.93	3.83	5.33	4.85	2.92	1.84	2.49	0.61	4.43	2.89	0.70	1.47	1.00	3.53	3.73	0	0.15	0	0	0	0
15	-5	4.79	6.34	7.08	5.70	5.70	4.21	4.25	3.14	3.38	2.80	0	2.24	1.25	1.91	2.85	1.03	1.92	0.76	1.39	0.88	1.25
15	0	3.98	5.39	4.93	3.87	5.59	4.08	6.30	4.50	6.00	4.82	0	1.46	0.31	0.68	1.53	0.24	1.45	0.24	1.47	0.71	1.54
15	7.5	2.37	4.03	4.07	2.90	4.04	2.16	6.02	3.37	7.33	5.45	1.60	0	0	0.11	0.59	0	0	0	0	0	0
15	15	2.12	5.01	6.21	4.23	4.23	1.01	4.80	0.84	6.62	3.94	1.10	0	0	0	1.07	0	0	0	0	0	0

REMARK: ◯ INDICATES THAT THESE DEFLECTIONS ARE THE SAME DEFLECTIONS AS THE SPRING THAT APPEARS IN THE CIRCLE

TABLE B-3. FUSLAGE CRUSH DISTANCE FOR 30 fps IMPACT, LANDING GEAR EXTENDED

AIRCRAFT IMPACT ATTITUDE, DEG.		SPRING/MASS LOCATION DEFLECTIONS, IN.																				
ROLL	PITCH	1	7	8	8′	12	12′	15	15′	16	16′	18″	24	30	31	31′	35	35′	38	38′	39	39′
0	-5	0.91	0.92	2.46	2.46	0.13	0.13	0	0	0	0	0	1	7	8	8′	12	12′	15	15′	16	16′
0	0	0.22	0.22	0.21	0.19	0.17	0.16	0.03	0.02	0	0	0										
0	7.5	0	0	0.81	0.80	0	0	0	0	0	0	0										
0	15	0.34	0.35	3.76	3.74	0	0	0	0	0	0	0										
5	-5	1.34	1.72	3.27	2.90	0.80	0.45	0	0	0	0	0	0.58	0.21	1.73	2.06	0	0	0	0	0	0
5	0	0.59	0.92	1.02	0.78	0.83	0.46	0.60	0.21	0.33	0.06	0	0.07	0	0.11	0.22	0	0	0	0	0	0
5	7.5	0.28	0.69	1.65	1.32	0.12	0	0	0	0	0	0	0	0	0.29	0.50	0	0	0	0	0	0
5	15	0.94	0.89	4.76	4.52	0	0	0	0	0	0	0	0.29	0.04	3.98	4.07	0	0	0	0	0	0
10	-5	1.07	1.62	3.12	2.56	0.61	0.26	0	0	0	0	0	0.51	0.49	1.32	1.60	0.18	0.07	0	0	0	0
10	0	0.40	0.73	0.78	0.63	0.69	0.25	0.81	0.15	0.63	0.20	0	0.18	0.26	0.65	0.50	0.07	0	0	0	0	0
10	7.5	0.03	0.56	1.54	1.22	0.08	0	0	0	0.46	0	0	0	0	1.01	0.91	0	0	0	0	0	0
10	15	0.87	2.34	5.24	4.19	0.53	0	0	0	0	0	0	0	0	2.25	2.31	0	0	0	0	0	0
15	-5	1.06	2.67	3.74	2.32	1.81	0.38	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	1.51	1.21	0.06	1.62	0	2.24	0.23	1.85	0.51	0	0	0	0.01	0	0	0	0	0	0	0
15	7.5	0	0	1.14	0	0.43	0	1.73	0	2.51	0.45	0	0	0	0	0	0	0	0	0	0	0
15	15	0	3.45	5.29	2.57	1.99	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0

REMARK: ( ) INDICATES THAT THESE DEFLECTIONS ARE THE SAME DEFLECTIONS AS THE SPRING THAT APPEARS IN THE CIRCLE

TABLE B-4. FUSELAGE CRUSH DISTANCE FOR 20 fps IMPACT, LANDING GEAR EXTENDED

AIRCRAFT IMPACT ATTITUDE, DEG.		SPRING/MASS LOCATION DEFLECTIONS, IN.																				
ROLL	PITCH	1	7	8	8'	12	12'	15	15'	16	16'	18''	24	30	31	31'	35	35'	38	38'	39	39'
0	-5	0	0	0.08	0.07	0	0	0	0	0	0	0	1	7	8	8'	12	12'	15	15'	16	16'
0	0	0	0	0	0	0	0	0	0	0	0	0										
0	7.5	0	0	0.44	0.43	0	0	0	0	0	0	0										
0	15	0	0	3.19	3.18	0	0	0	0	0	0	0										
5	-5	0	0	0.05	0.06	0	0	0	0	0	0	0	0	0	0.12	0.09	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	7.5	0	0	0.16	0.25	0	0	0	0	0	0	0	0	0	0.72	0.59	0	0	0	0	0	0
5	15	0	0	3.46	3.26	0	0	0	0	0	0	0	0	0	2.59	2.77	0	0	0	0	0	0
10	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	15	0	0	3.49	2.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	15	0	0	2.88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

REMARK: ◯ INDICATES THAT THESE DEFLECTIONS ARE THE SAME DEFLECTIONS AS THE SPRING THAT APPEARS IN THE CIRCLE

TABLE B-5. FUSELAGE CRUSH DISTANCE FOR 35 fps IMPACT, LANDING GEAR RETRACTED

AIRCRAFT IMPACT ATTITUDE, DEG.		SPRING/MASS LOCATION DEFLECTION, IN.																				
ROLL	PITCH	1	7	8	8'	12	12'	15	15'	16	16'	18''	24	30	31	31'	35	35'	38	38'	39	39'
0	-5	5.71	5.74	7.81	7.76	4.88	4.87	6.85	6.84	8.03	8.02	5.10	(1)	(7)	(8)	(8')	(12)	(12')	(15)	(15')	(16)	(16')
0	0	7.05	7.06	6.76	6.84	7.24	7.19	7.42	7.60	7.98	7.97	3.84										
0	7.5	6.55	6.57	7.55	7.51	5.79	5.77	4.73	4.73	6.61	6.59	6.89										
0	15	6.05	6.07	8.06	8.00	4.44	4.41	0	0	0.63	0.62	7.92										
5	-5	5.87	6.77	8.67	7.87	5.54	4.88	6.89	6.77	8.11	8.03	5.14	4.22	3.45	5.67	6.39	4.01	4.20	6.50	6.58	7.87	7.87
5	0	6.88	7.88	7.43	6.59	7.99	6.96	8.35	7.37	8.34	7.86	3.19	5.30	5.46	5.11	4.94	5.61	5.57	6.12	6.39	6.60	6.87
5	7.5	6.37	7.12	8.12	7.62	6.21	5.44	5.72	4.57	8.20	7.40	6.84	5.13	4.60	6.59	6.89	3.41	4.05	1.42	2.43	4.22	4.99
5	15	6.33	7.48	8.91	8.09	6.08	4.86	1.78	0.52	2.76	1.89	7.83	4.34	3.39	6.09	6.74	1.65	2.69	0	0	0	0
10	-5	5.23	7.38	9.14	7.34	6.03	4.42	7.38	6.50	8.41	7.97	4.95	1.56	0.37	1.90	3.50	1.28	2.17	4.64	5.15	6.58	6.89
10	0	6.26	8.26	7.62	5.97	8.35	6.31	8.81	6.85	8.57	7.49	1.95	2.84	2.49	2.05	2.33	2.79	3.18	3.61	4.16	4.26	4.74
10	7.5	5.94	7.34	8.38	7.43	6.45	4.90	6.75	4.36	9.33	7.78	6.50	3.56	2.56	5.10	5.73	1.06	2.22	0	0.04	1.54	3.07
10	15	5.70	8.28	9.19	7.27	7.11	4.42	3.56	0.81	4.76	3.02	7.77	1.07	0	1.62	3.32	0	0	0	0	0	0
15	5	4.27	7.70	9.34	6.50	6.36	3.54	7.93	6.00	8.71	7.66	4.00	0	0	0	0.10	0	0	2.26	2.99	4.20	4.87
15	0	5.14	8.57	7.73	4.92	8.63	5.13	9.11	6.02	8.60	6.85	0.46	0.91	0.08	0.02	0.64	0.25	1.19	0.78	1.85	1.50	2.37
15	7.5	4.71	6.83	8.40	7.03	5.76	3.37	7.79	4.11	10.38	8.01	5.97	1.22	0	3.82	4.50	0	0	0	0	0	0.76
15	15	4.58	8.68	8.99	5.81	7.80	2.88	5.50	1.07	6.80	4.16	7.76	0	0	0	0	0	0	0	0	0	0

REMARK: ( ) INDICATES THAT THESE DEFLECTIONS ARE THE SAME DEFLECTIONS AS THE SPRING THAT APPEARS IN THE CIRCLE

TABLE B-6. FUSELAGE CRUSH DISTANCE FOR 30 fps IMPACT, LANDING GEAR RETRACTED

AIRCRAFT IMPACT ATTITUDE, DEG.		SPRING/MASS LOCATION DEFLECTIONS, IN.																				
ROLL	PITCH	1	7	8	8'	12	12'	15	15'	16	16'	18''	24	30	31	31'	35	35'	38	38'	39	39'
0	-5	5.27	5.28	7.54	7.51	4.41	4.40	6.02	6.01	7.28	7.28	4.43	(1)	(7)	(8)	(8')	(12)	(12')	(15)	(15')	(16)	(16')
0	0	6.00	6.01	5.29	5.27	6.39	6.37	7.25	7.23	7.70	7.69	3.64										
0	7.5	5.80	5.80	7.21	7.18	4.83	4.82	3.70	3.70	5.76	5.74	6.26										
0	15	5.80	5.82	7.62	7.58	4.48	4.45	0.44	0.42	0	0	6.79										
5	-5	5.32	6.28	8.38	7.51	4.97	4.27	6.06	5.86	7.49	7.42	4.75	3.46	2.67	5.10	5.85	2.84	3.23	5.52	5.61	7.17	7.23
5	0	6.35	7.29	6.70	5.94	7.48	6.53	8.01	7.11	8.09	7.58	2.78	4.62	4.04	3.76	4.10	4.28	4.94	5.18	5.86	5.91	6.35
5	7.5	5.88	6.66	7.80	7.21	5.77	4.91	5.45	4.26	7.65	6.85	6.24	4.45	3.76	5.53	6.02	2.64	3.36	0.83	1.97	3.61	4.39
5	15	5.97	7.05	8.50	7.69	5.75	4.58	1.90	0.66	1.56	0.69	6.76	3.98	3.06	5.46	6.13	1.52	2.52	0	0	0	0
10	-5	4.50	6.92	8.86	7.07	5.55	3.88	6.71	5.84	7.87	7.43	4.49	1.01	0	1.23	2.98	0.41	1.37	4.07	4.51	6.02	6.30
10	0	5.88	7.89	7.24	5.60	8.00	5.98	8.51	6.61	8.26	7.16	1.41	2.19	1.25	0.85	1.51	1.59	2.57	2.53	3.58	3.37	4.12
10	7.5	5.36	6.66	7.98	7.08	5.68	4.22	6.34	3.94	8.91	7.34	6.00	3.10	2.10	4.54	5.22	0.64	1.71	0	0	0.95	2.51
10	15	5.41	7.85	8.78	6.90	6.78	4.21	3.59	0.93	3.55	1.82	6.69	0.90	0	1.09	2.80	0	0	0	0	0	0
15	-5	3.85	7.30	9.06	6.17	5.88	2.96	7.29	5.46	8.25	7.23	3.72	0	0	0	0	0	0	1.62	2.55	3.83	4.50
15	0	4.70	8.14	7.28	4.46	8.24	4.85	8.84	5.74	8.29	6.46	0	0.13	0	0.11	0	0	0.35	0	1.11	0.60	1.62
15	7.5	4.05	6.06	8.01	6.70	4.88	2.51	7.41	3.70	9.98	7.60	5.44	0.63	0	2.80	3.85	0	0	0	0	0	0.20
15	15	4.30	8.25	8.63	5.50	7.42	3.32	5.26	0.79	5.56	2.92	6.68	0	0	0	0	0	0	0	0	0	0

REMARK: ( ) INDICATES THAT THESE DEFLECTIONS ARE THE SAME DEFLECTIONS AS THE SPRING THAT APPEARS IN THE CIRCLE.

TABLE B-7. FUSELAGE CRUSH DISTANCE FOR 25 fps IMPACT, LANDING GEAR RETRACTED

AIRCRAFT IMPACT ATTITUDE, DEG.		SPRING/MASS LOCATION DEFLECTION, IN.																				
ROLL	PITCH	1	7	8	8′	12	12′	15	15′	16	16′	18″	24	30	31	31′	35	35′	38	38′	39	39′
0	-5	4.83	4.83	7.12	7.11	4.04	4.03	4.47	4.46	5.07	5.07	1.05	(1)	(7)	(8)	(8′)	(12)	(12′)	(15)	(15′)	(16)	(16′)
0	0	4.44	4.44	3.87	3.85	4.88	4.87	6.21	6.21	6.93	6.93	3.02										
0	7.5	4.00	4.00	5.08	5.08	3.36	3.34	2.62	2.62	4.92	4.91	5.63										
0	15	4.96	4.95	7.15	7.14	3.47	3.47	3.45	3.35	0.11	0.11	5.79										
5	-5	4.66	5.68	7.98	7.08	4.36	3.58	4.73	4.42	5.76	5.58	2.22	2.73	1.90	4.33	5.15	1.71	2.25	3.59	3.85	4.97	5.09
5	0	5.20	6.12	5.42	4.61	6.47	5.57	7.43	6.58	7.69	7.18	2.37	3.39	2.52	2.01	2.73	2.98	3.81	4.25	5.02	5.18	5.66
5	7.5	4.89	5.80	6.62	5.90	5.22	4.27	5.13	3.92	6.96	6.16	5.57	3.10	2.21	3.44	4.14	1.52	2.42	0.33	1.51	2.87	3.66
5	15	5.38	6.32	7.90	7.20	5.06	4.09	1.76	0.64	0.98	0.12	5.80	3.67	2.83	6.40	6.20	1.43	2.29	0	0	0	0
10	-5	4.65	6.26	8.41	6.52	4.82	3.17	5.65	4.82	6.74	6.31	2.95	0.25	0	0.40	2.20	0	0.49	2.96	3.54	4.75	5.10
10	0	5.27	7.23	6.41	4.81	7.44	5.51	8.10	6.24	7.90	6.76	0.89	1.80	0.55	0.25	1.26	0.85	2.13	1.67	3.05	2.60	3.53
10	7.5	4.50	5.79	7.14	6.21	4.94	3.49	5.85	3.47	8.39	6.82	5.43	2.14	0.99	3.27	4.06	0	0.96	0	0	0.31	1.88
10	15	5.07	7.22	8.34	6.66	6.16	3.88	3.32	0.81	2.91	1.18	5.75	0.98	0	3.04	3.12	0	0	0	0	0	0
15	5	3.14	6.66	8.53	5.65	5.22	2.30	6.55	4.90	7.58	6.61	2.84	0	0	0	0	0	0	0.86	2.02	3.11	3.84
15	0	4.18	7.50	6.46	3.76	7.73	4.45	8.54	5.39	7.97	6.04	0	0	0	0	0	0	0	0	0.30	0	0.80
15	7.5	3.18	4.98	6.87	5.63	4.08	1.83	7.08	3.41	9.47	7.10	4.78	0.08	0	2.81	3.04	0	0	0	0	0	0
15	15	4.02	7.68	8.17	5.37	6.84	3.06	4.78	0.71	4.92	2.27	5.70	0	0	0	0	0	0	0	0	0	0

REMARK: ( ) INDICATES THAT THESE DEFLECTIONS ARE THE SAME DEFLECTIONS AS THE SPRING THAT APPEARS IN THE CIRCLE

APPENDIX C

DETAIL PLOTS OF OCCUPANT SEAT STROKE FROM PHASE II STUDY OF COUPLED LANDING GEAR

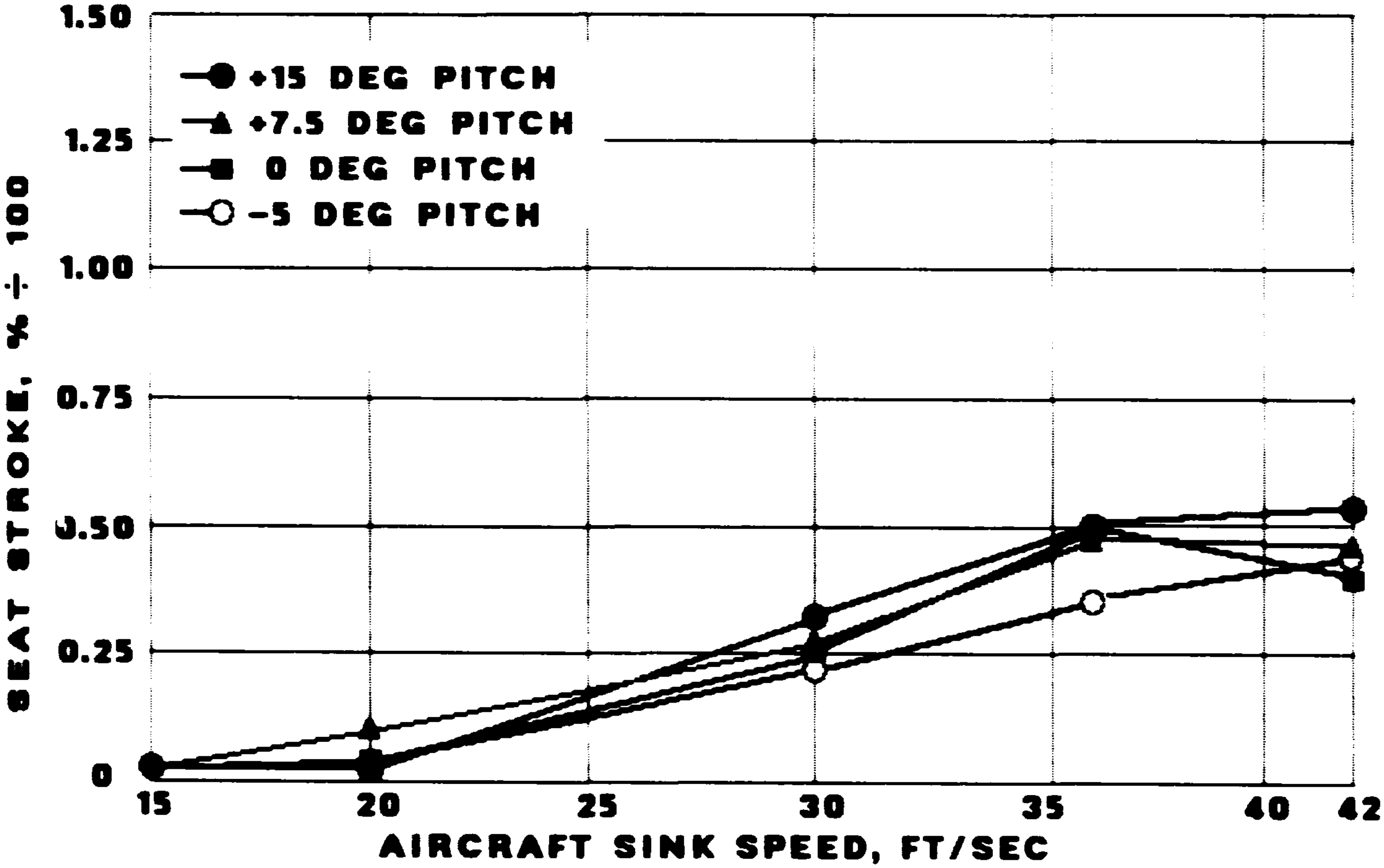

Figure C-1. Occupant seat stroke; 0 degree roll, landing gear extended.

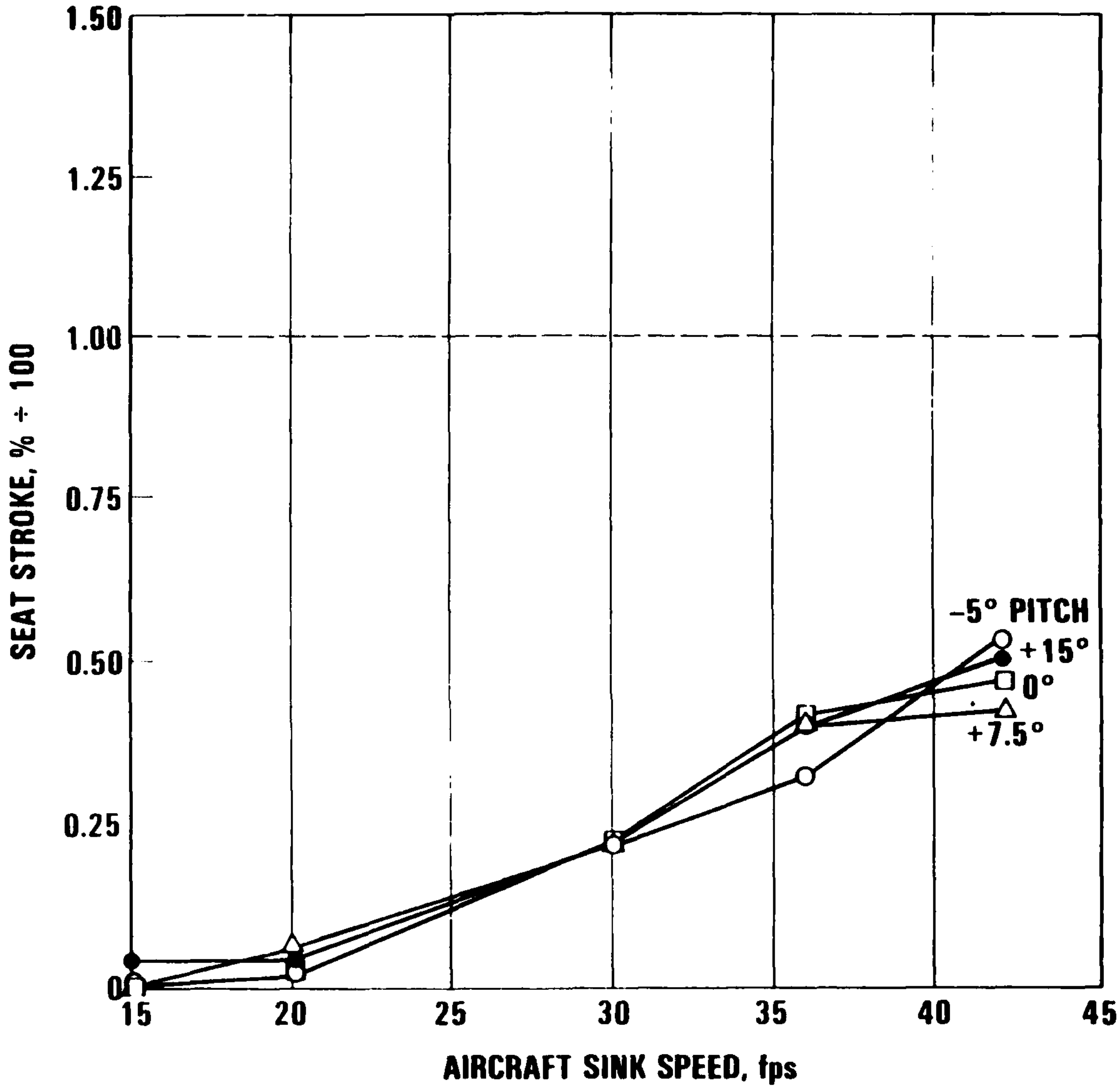

Figure C-2. Occupant seat stroke; 5 degree roll, landing gear extended.

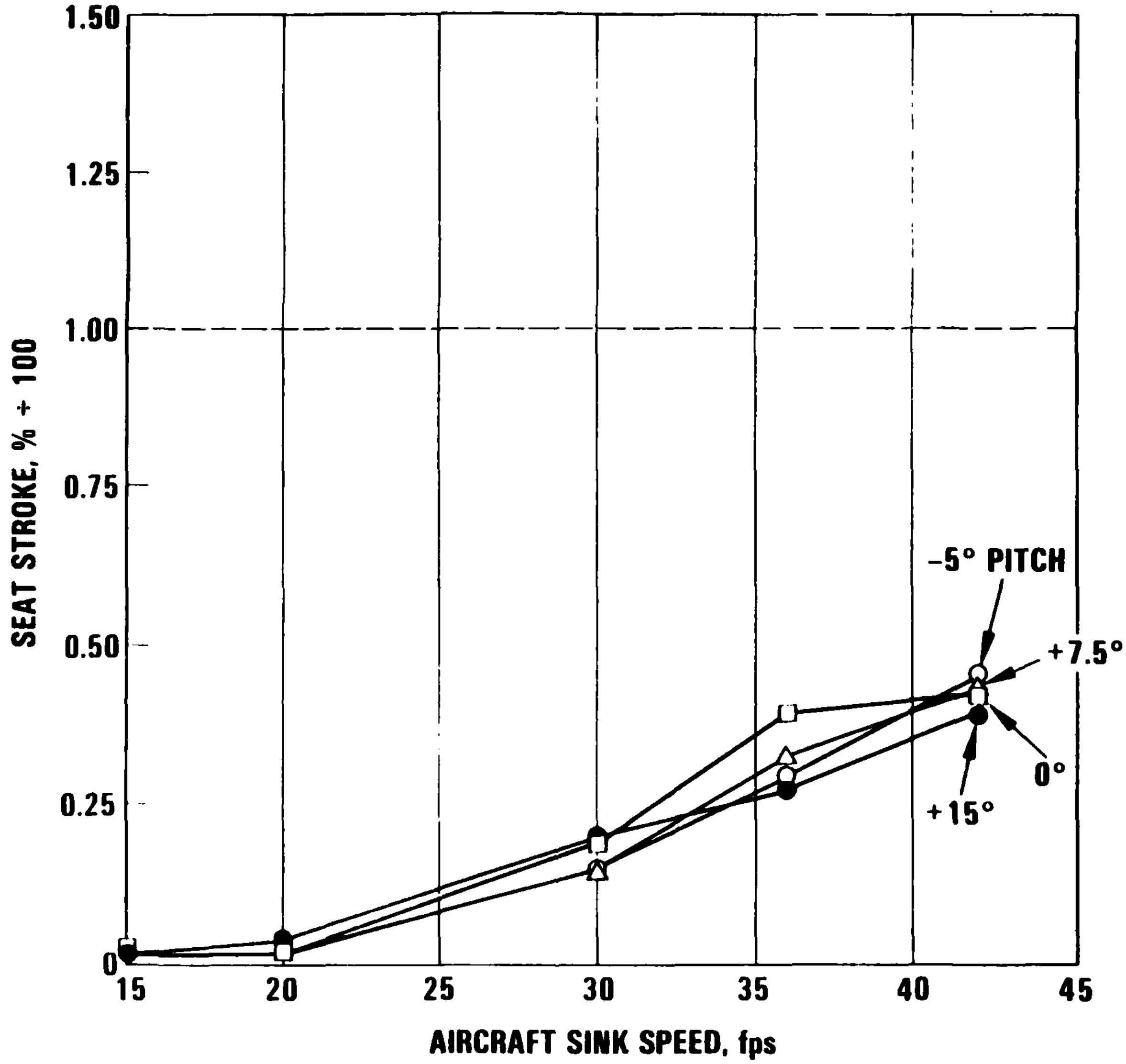

Figure C-3. Occupant seat stroke; 10 degree roll, landing gear extended.

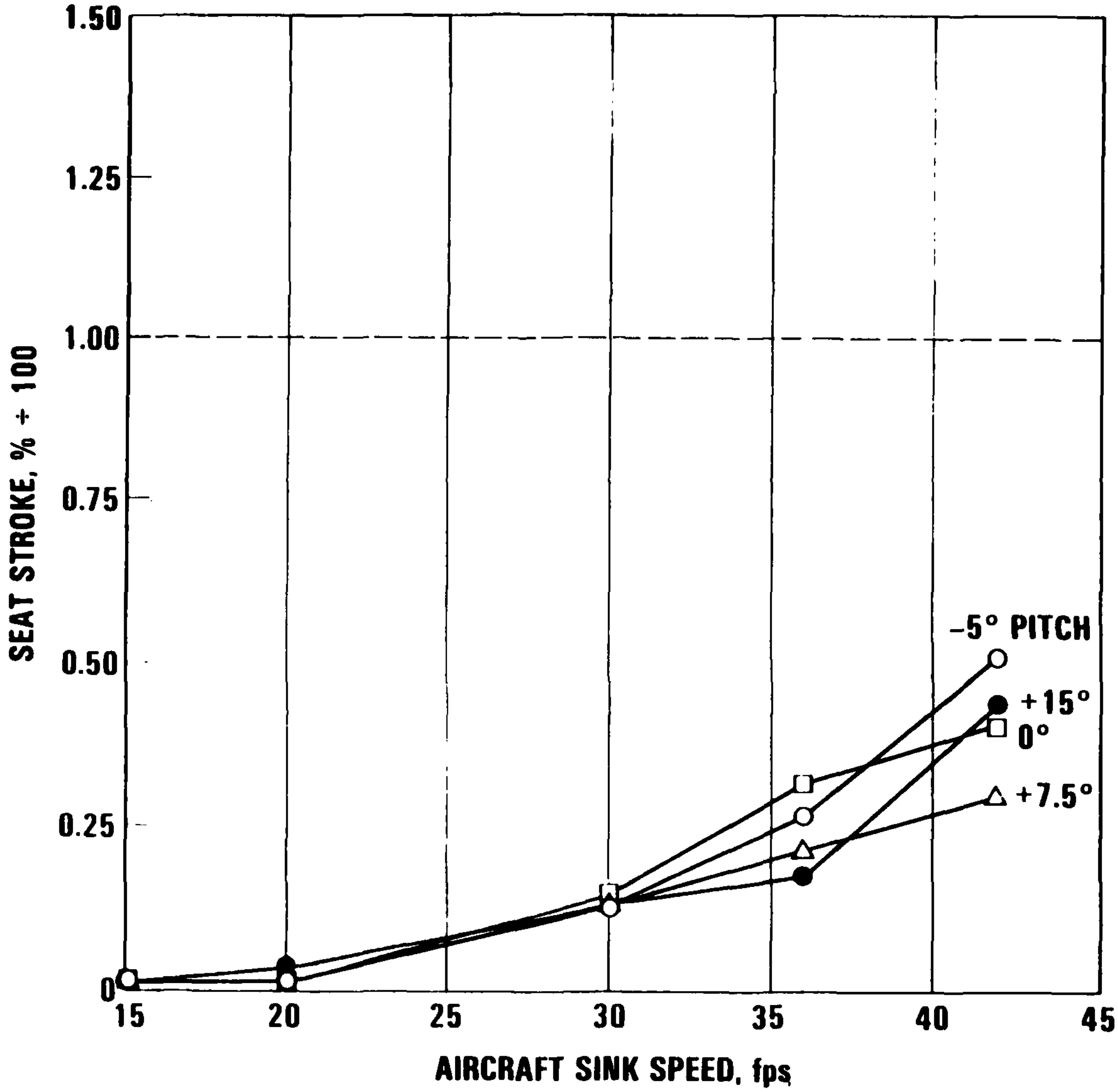

Figure C-4. Occupant seat stroke; 15 degree roll, landing gear extended.

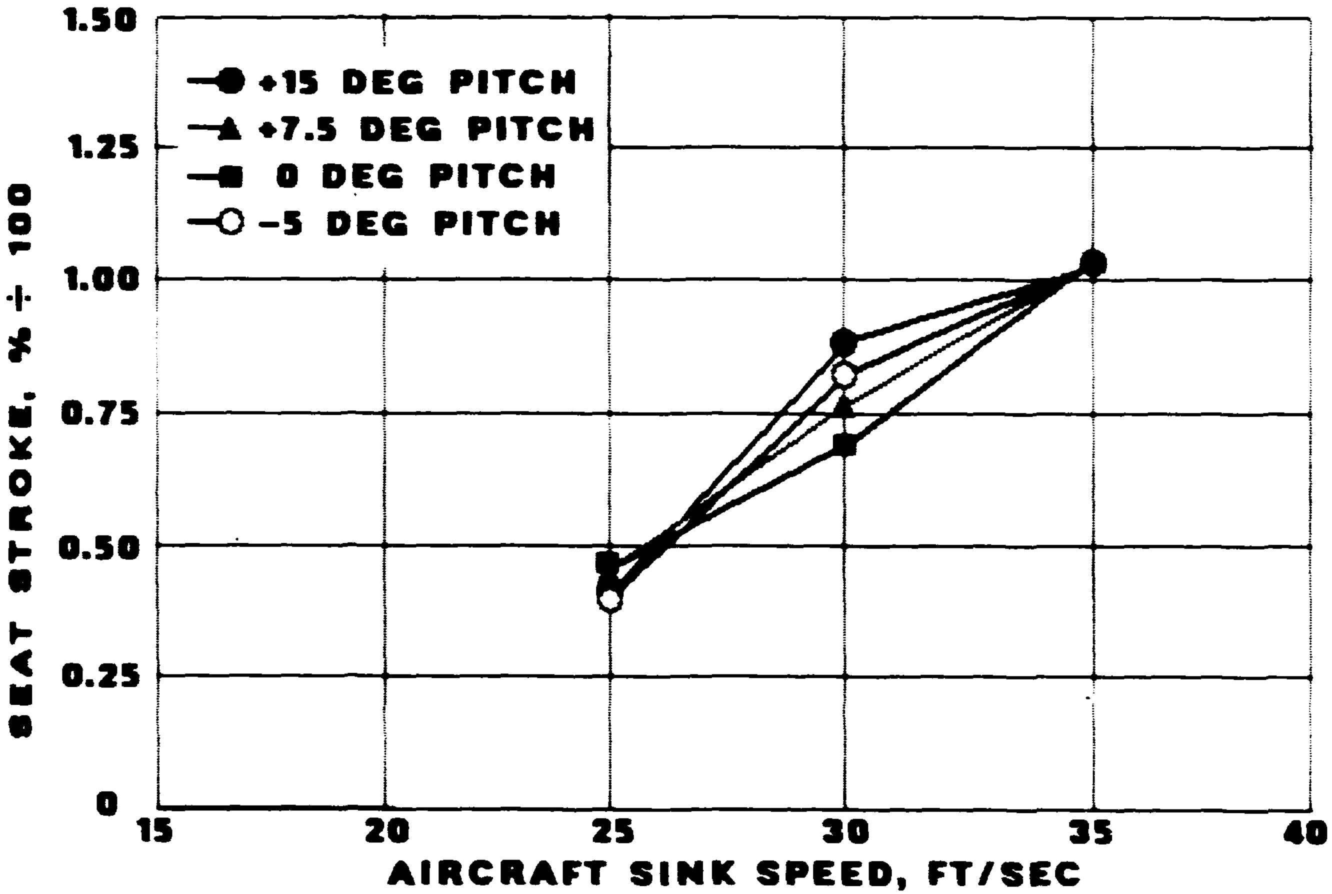

Figure C-5. Occupant seat stroke; 0 degree roll, landing gear retracted.

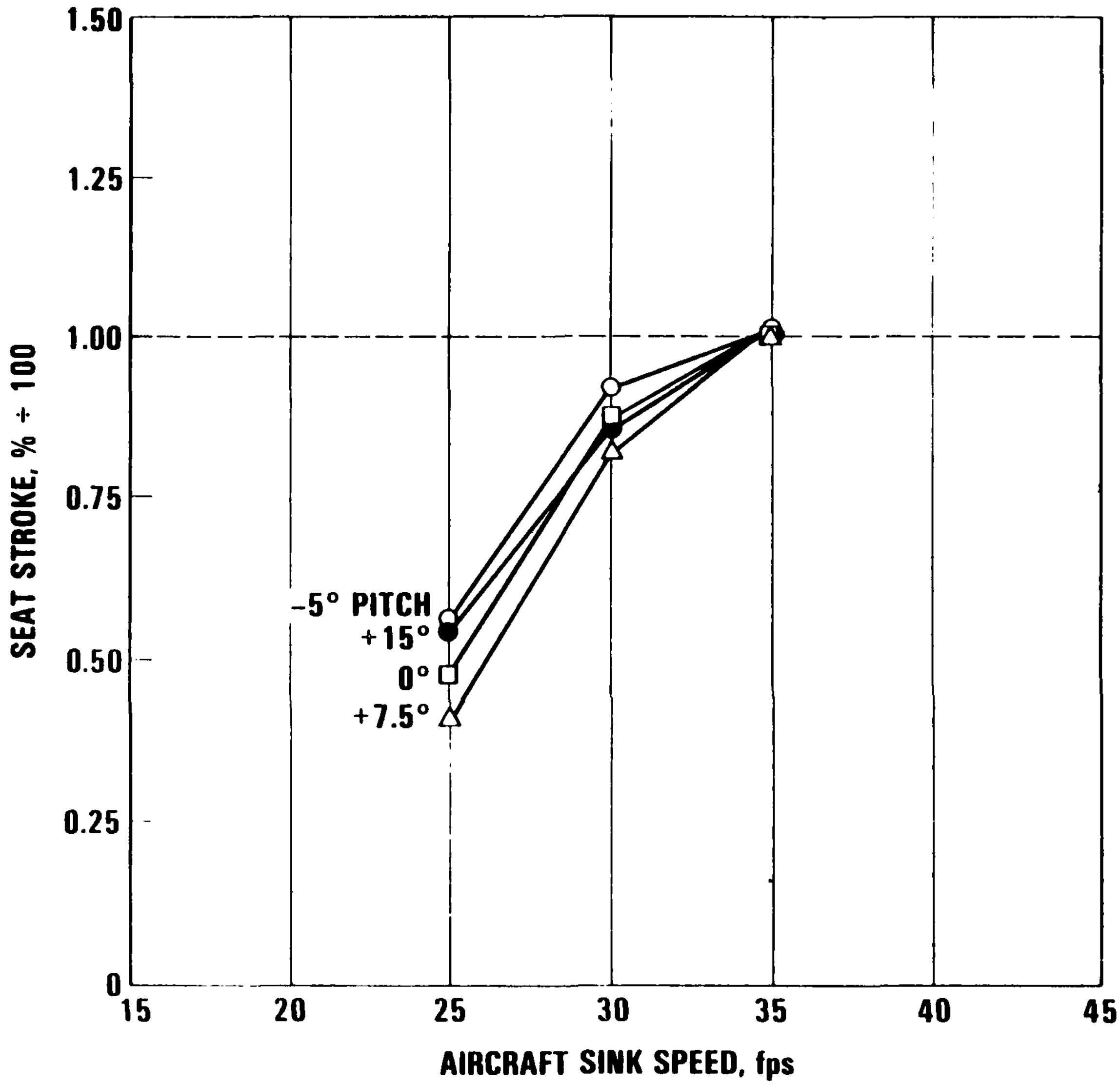

Figure C-6. Occupant seat stroke; 5 degree roll, landing gear retracted.

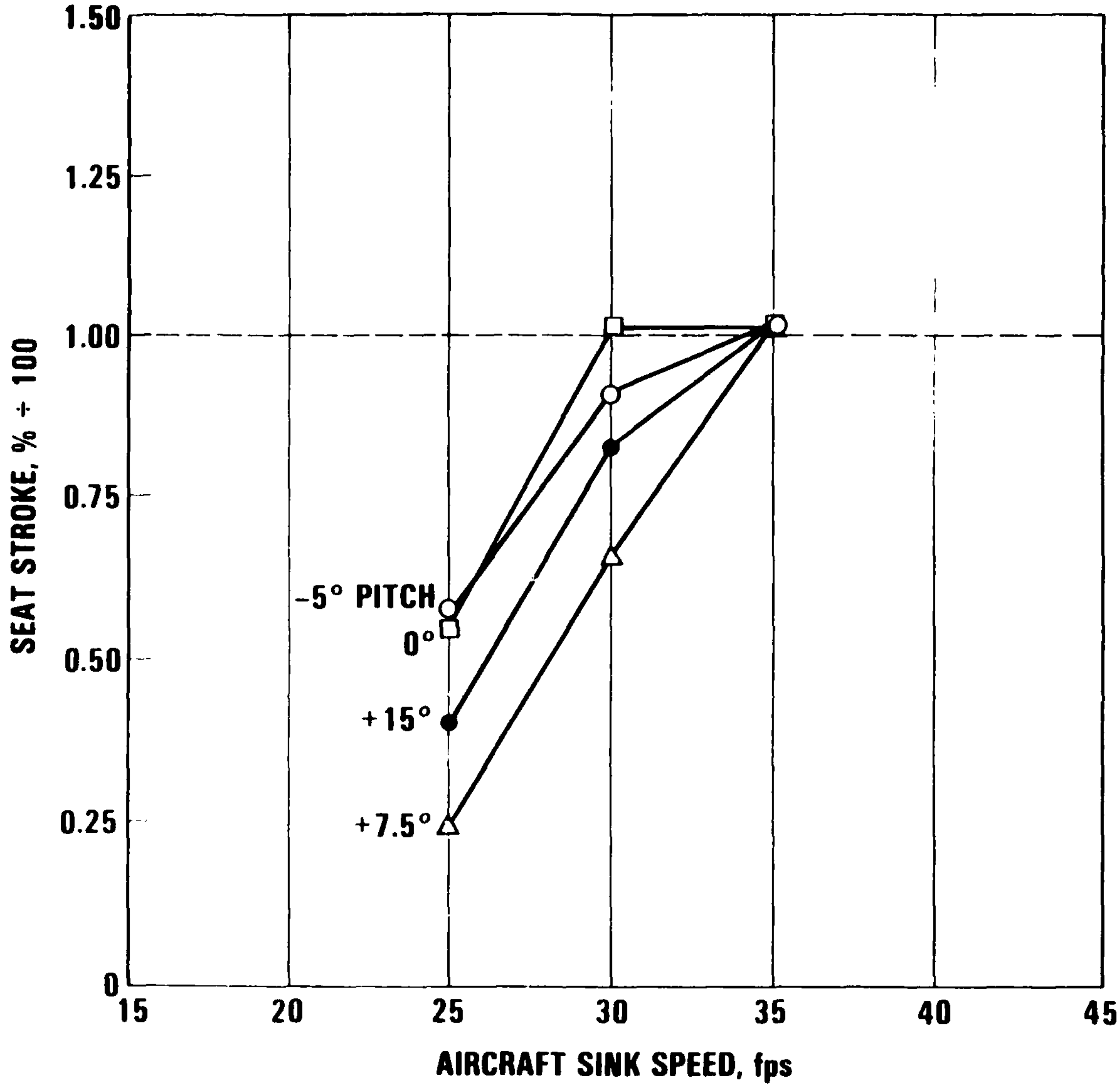

Figure C-7. Occupant seat stroke; 10 degree roll, landing gear retracted.

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